Identifying and developing technology for enabling small producers to pursue the residual oil zone (ROZ) fairways in the Permian Basin San Andres. Final Report

Principal Investigator: Dr. Robert C. Trentham, Center for Energy and Economic Diversification, Univ. of Texas of the Permian Basin
Co-Principal Investigator: L. Stephen Melzer, Melzer Consulting
Investigator: David B. Vance, Arcadis U.S., Inc.
Investigator: Mr. Vello Kuuskraa, Advanced Resources International, Inc.
Investigator: Ms. Robin Petrusak, Advanced Resources International, Inc.

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Dr. Robert Trentham
Director, Center for Energy and Economic Diversification
The University of Texas of the Permian Basin
4901 E. University Blvd
Odessa, TX 79762

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ABSTRACT

Identifying and Developing Technology for Enabling Small Producers to Pursue the Residual Oil Zone (ROZ) Fairways of the Permian Basin, San Andres Formation

A substantial improvement in the understanding of the intervals below the oil/water contacts has widened the perspective from transition zone concepts to a broader term called residual oil zones (ROZs). This is a notion that the oil/water contact could have migrated upward in geological time after the oil entrapment stage leaving residual oil below the present-day oil water contact. The work is also showing that the zone can be quite volumetrically significant and occur even where no overlying main payzone is present. Examples of these ROZs are now being identified in many oil basins around the world. The Permian Basin region of west Texas and southeastern New Mexico has been used as the reference model for the research over 20 years into their origins, distributions and properties.

Three different types of ROZs have been characterized: 1) those due a late stage regional tilt of the basin, 2) a temporary or permanent breach of the sealing formation atop the oil entrapment, or 3) an uplift on one side of a basin which allow for hydrodynamic forces to laterally sweep very slowly through the basin to exit downdip on the other side of the basin. This third type is the one extensively studied herein.

The first step in characterizing the type of ROZ involves understanding the tectonic history of a basin and establishing the regional geological framework for the formations to be examined. This study describes this while focusing on the Permian aged San Andres formation of the Permian Basin which can often include over 1400 feet of total vertical section and consisting of predominately dolomites and limestones.

This study identified and outlines processes of microbial activity playing very significant roles in affecting both the oil and rock properties. The sulfate-reducing bacteria (SRB) are not only responsible for the sour nature of the oil and gas but also some of the diagenetic changes the formation has undergone where the water sweep has occurred. All the evidence points to the SRB involvement in creating a more oil wet system in carbonate ROZs. The microbes need to reside in water and capture their metabolic energy off of electron exchanges. They use the activity level of sulfur sourced from the anhydrite present within the carbonate rock system and carbon from the transporting oil. The SRB's effects have not seen a concentrated level of study in the industry due to their lack of importance in the main payzones and a microbial self limitation (MSL) process inhibiting their effects there.

Techniques for identifying and characterizing ROZs are set out in the form of a “cookbook” of classic evidence and observations along with their ROZ interpretation. Case histories are outlined including one in the Permian Basin (San Andres formation), Big Horn Basin (Tensleep sandstone) and Williston Basin (Red River formation).

In order to establish the commercial significance of the ROZ resource in the San Andres formation in the Permian Basin, it was necessary to understand and map their presence and then characterize their oil and rock properties. The early stage ROZ mapping identified an inititial four-county resource area that was later expanded to eight additional counties. The results of the 12-county study area are presented suggesting that approximately 190 billion barrels of oil in place are present here, that 135 billion of that is high quality i.e., porosity greater than 8% and oil saturations greater than 25%, and that 17.5 billion barrels are producible in the original 4-county area using CO_2 EOR techniques at an oil price of $80/barrel and $1.92/mcf.

Finally, the ROZ study has serendepitously led to a more complete understanding of a new horizontal drilling play wherein immobile oil can produced from the upper portions of the ROZ utilizing horizontal drilling and reservoir stimulation methods. The new play has been dubbed “Depressuring the Upper ROZ” (DUROZ) or “Depressuring EOR” (DEOR) since reducing the pressures on the residual oil causes breakout of entrained gas which mobilizes a portion of the oil. Some case histories are presented and the idea of using DUROZ as a pre-stage to CO_2 EOR and CO_2 storage has been introduced.

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Chapter 1: INTRODUCTION AND BACKGROUND

Author: L.S. Melzer

Zones within many formations with natural[1] residual oil saturations have been occasionally noted in the literature[2] but first put into a basin context in a report by Melzer (Ref 1.1) and subsequently modeled by Trentham, Melzer, Vance et al (Ref 1.2) in 2006 and 2012, respectively. The work built upon earlier efforts looking at basin-wide hydrodynamics generally motivated by explaining the displacement of oil to hydrodynamic traps (Refs 1.3-1.5). The cited work in the Permian Basin recognized that it was about understanding from where the oil was displaced. Those paleo entrapments had not been swept completely of their oil and the residual oil left behind now had commercial significance. If the remaining oil left behind was sufficiently robust in concentration it could be flooded by enhanced oil recovery techniques. At the time of this writing, there are fifteen commercial CO_2 Enhanced Oil Recovery (EOR) projects exploiting the residual oil zones of the Permian Basin.

New terminologies were required to describe the current state of the paleo entrapments that had been altered from the earlier first stage entrapments. The phrase Residual Oil Zone (ROZ) was adopted to differentiate these from the commonly cited transition zones beneath many oil fields. We note herein that it is fully recognized that the mechanics of transition zones (i.e., capillary forces and surface tension) are indeed important but are lacking to explain the ROZs now being observed around the world.

While gathering the field data in the Permian Basin, it was observed that these intervals of residual oil included vast regions of ROZs without an overlying main pay zone. Deeper wells and dry holes drilled in these regions provided the key data control, but since no main pay zone (MPZ) field development was possible, new wells would be required to commercially exploit the residual oil. As a result, the term “greenfield” was adopted and is utilized herein to describe those areas in contrast to the ROZs beneath the producing oil fields (“brownfields) where existing wells can be deepened to exploit the ROZs via EOR techniques.

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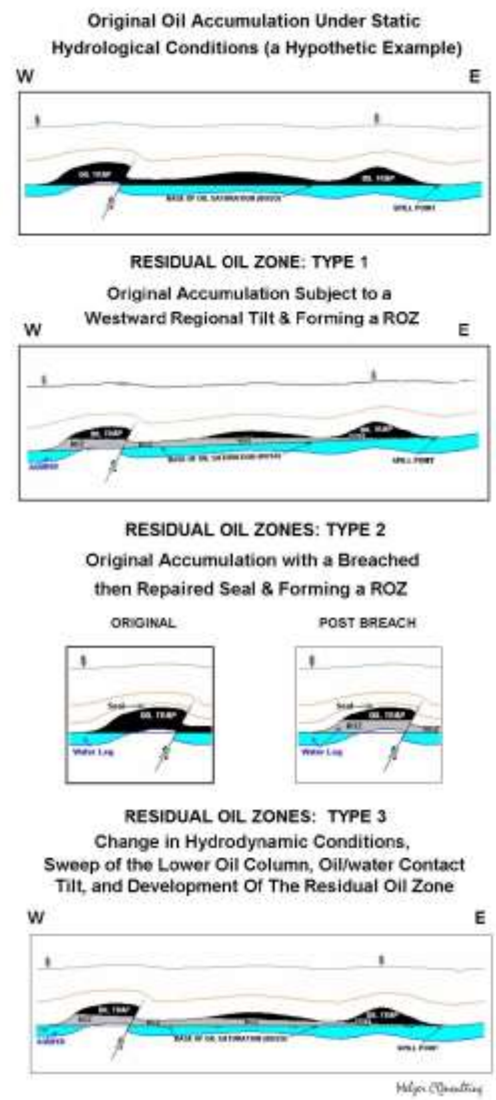
[1] Natural as created by nature and opposed to man-made as in a water flood

[2] Example residual oil references in the SPE/AAPG literature

The interest in ROZs ramped up in the Permian Basin when commercial demonstration EOR projects began to yield results in the San Andres formation where an estimated 12,000 barrels of oil per day are being produced today from the brownfield ROZs in fifteen different projects. All of these EOR projects are injecting carbon dioxide (CO_2) to change the properties of the residual oil to make it producible.   The next phase of commercial exploitation of the ROZ has begun as two new projects have been implemented in a greenfield. All projects involve only the San Andres dolomite formation of the Permian Basin although the research has now identified other formations and other basins with ROZs, namely, the Big Horn and Williston Basins reported upon herein.

Figure 1.1 – Types of ROZs



In speaking to the origin of ROZs, three types of ROZs have been proposed (Refs 1.1, 1.6) and all require a post-entrapment tectonic adjustment of the oil bearing basin. The first type (Type 1) is a basin-wide tilt which readjusts the oil/water contact in the paleo oil entrapment, the second (Type 2) involves the escape of oil or gas through the seal and water encroachment from below into the paleo oil leg. The third type (Type 3) involves an uplift on one side of a paleo basin wherein meteoric waters can infiltrate into, and laterally migrate through, an oil filled reservoir while displacing oil and moving the fluids out to the outcrops on the downdip side of the basin. Figure 1.1 attempts to graphically portray the three types of ROZs.

In order to gain an appreciation of the size of oil resource involved, an early assessment of brownfield oil-in-place (OIP) resources was conducted for the San Andres formation in the Permian Basin (Ref 1.7). In many cases, the ROZ oil prize beneath an oilfield more than doubled the in-place oil resource of the field (Ref 1.8). The research also observed that many areas of "Greenfield" residual oil occurred in areas of dry holes and the intervals of shows of oil had no main pay zone (MPZ) above them. Once the controversial greenfield concept gained some traction, the Research Partnership to Secure Energy for America was approached to try and model the hydrodynamic processes to see if modern modeling technology was in concert with the observations from drilling and formation testing. An area of the Permian Basin San Andres formation was chosen, drill stem test, wireline log and core data were collected to characterize the fairway area and model the hydrodynamic sweep. Those efforts were reported in Ref 1.9 and referred to herein as results from the RPSEA I study.

Once the hydrodynamic modeling appeared consistent with the field data gathered on the RPSEA I study area and showed the concept of ROZ greenfields to be valid, more work was clearly needed. Preliminary mapping of the greenfields in other areas of the Permian Basin pointed to very large 'fairways' of sweep within the San Andres formation. The study described herein was conceived in part to be the first large scale attempt to gather the needed data and place a figure on the greenfield residual oil resources; the San Andres oil-in-place ROZ resource in the Permian Basin was the obvious first choice.

The magnitude of the task was enormous of course so a cautionary note is appropriate here. The greenfield resource is so vast and variable in its nature, it can only be classified as a work in progress to adequately quantify the oil-in-place resource. Within the Permian Basin, the study herein limited its scope to several key counties and to the San Andres formation. As one moved south into the Basin, the ROZs found their way into the Grayburg formation and, in moving east, into the Glorieta, Clearfork and Coleman Junction formations. None of these formations or areas were able to be studied to anywhere near the degree of the San Andres in the northern Permian Basin. As it has taken almost a century to establish the magnitude of the oil-in-place figures for the main pay zones, it will be some time before the size of the ROZ prize just within the PB is fully characterized. However, the area believed to have the maximum resource potential was chosen and is reported herein.

Another term referred to above and that was coined to describe the areal distribution of ROZs is "fairway." The continuing studies have shown that the laterally swept, Type 3 ROZs present in the Permian Basin move the flushing waters through the high energy deposited carbonates (reefal, open shelf, shoals) that have allowed the west side meteoric derived waters to infiltrate to the heart of the Basin and out to the outcrops on the eastern rim of the Basin. Mapping of the various flow pathways (fairways) has been the goal of much of the work in this effort (Chapter 3) but the corollary challenge has been to gather important ROZ reservoir property data (Chapter 2) and better understand the levels of oil saturation and the processes that are affecting both the saturations and properties of the oil and rocks within the ROZs. While recognizing that biogenetic mechanisms are inhibited in the main payzones (MPZs) but are active in the mobile water flushed, dynamic environments of the ROZs, this report has had to address the role of microbes on both the oil and rocks. These processes are shown to be critical in the (San Andres) carbonate world and are described in some detail Chapter 4. Much work still remains to be done there but recognition of the role of microbial transformations of the rocks and oils will, at least, kick-start new studies and incorporate much work done on anaerobic processes for other applications.

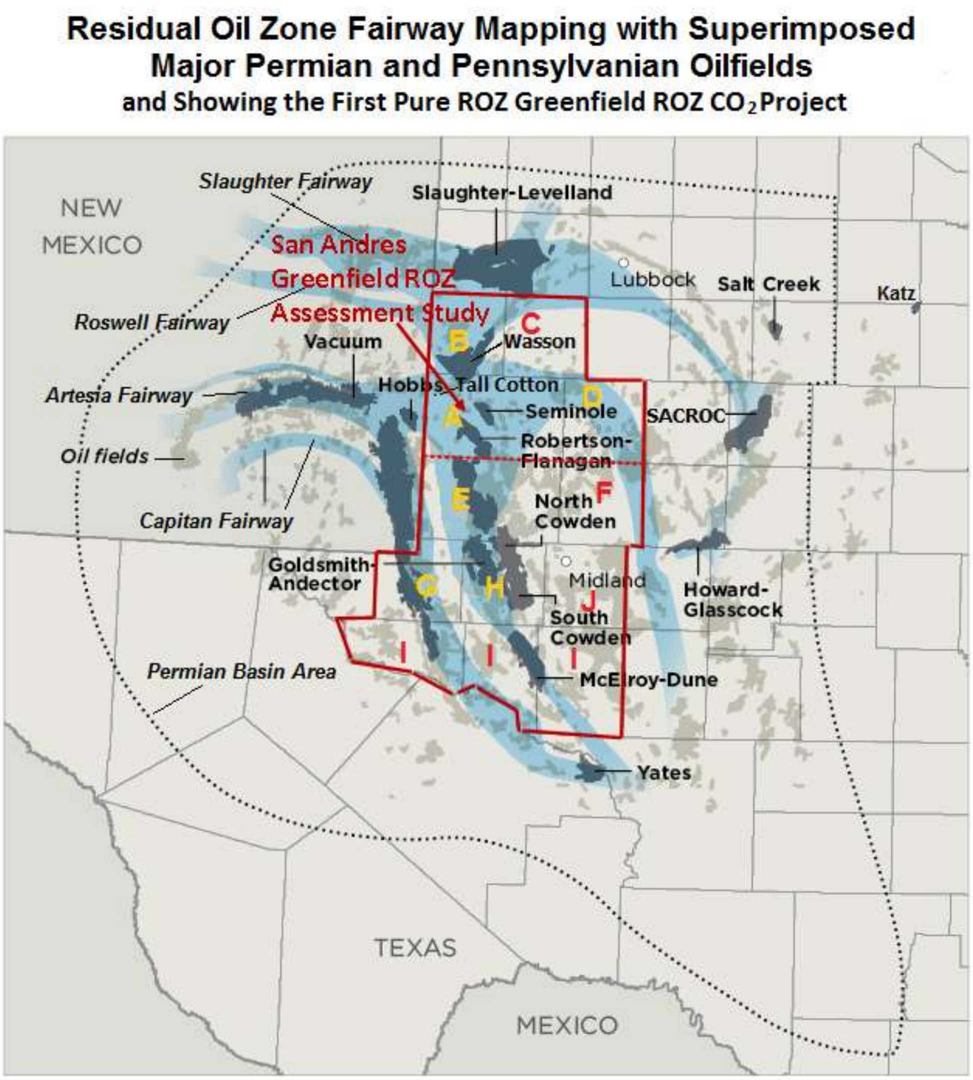
Chapter 5 brings together the results of the data gathering, mapping and biogenetic processes in the perspective of core sections that have been obtained. Comparisons of MPZs and ROZs are examined with the available core and also with wireline logs looking for common properties and characteristics that help one identify the presence of a ROZ. This takes the form of a "cookbook" to assist independents, major oil companies, and researchers alike to guide those investigators as they attempt to identify and characterize ROZs. The cookbook has been formulated with an eye on data that has already been archived in order to direct the individual to an area to gather new and inevitably more expensive data.

A particular frustration of the project revolved around utilization of seismic data to assist in identifying and 3-D mapping of some particular attribute or characteristic of a ROZ. A geographical area of study was identified that possessed a relatively modern and available 3-D reflection seismic survey, but access to the data for the desired re-analysis became too expensive for the scope of the project. The would-be goals of the task are identified in Chapter 6 presented in the hope that other research might be conceived from the preliminary ideas introduced therein.

One of the key objectives of the research program was to scope out the size of the oil-in-place (OIP) prize in the San Andres formation ROZs of the Permian Basin. As mentioned earlier, previous work found a brownfield resource of 30.7 billion barrels of OIP beneath 56 fields on the Central Basin Platform, Northern Shelf and Eastern Shelf (Figure 1.2 – Ref 1.8) The challenge of this work was to use the newly generated maps of the ROZs within the Permian Basin San Andres formation presented in Chapter 3 together with the residual oil saturations to estimate the OIP resource base. To do this, both brownfields and greenfields needed to be addressed. The scope of the project was such that a determination had to be made to limit the geographic area to a group of key counties. Some of the Northern Shelf, the north reaches of the Central Basin Platform and a rich fairway through Dawson County were included in the geographical area (Fig. 1.2 – counties labelled "A-D"). The scope of investigation was then expanded to include eight more counties located to the south of the first four as shown on Figure 1.2 (counties “E-I”).

When commercial exploitation is involved, one of the most difficult challenges is to identify the portion of the OIP that would be technically recoverable using EOR techniques and an approach was chosen by ARI to classify the ROZ resources into two categories: 1) of higher quality where the average porosity and residual oil saturations of the interval exceeded the threshold values and 2) where residual oil was shown to be present but fell below one of the two threshold values. The methodology used and results are presented in Chapter 7.

Figure 1.2



During the course of the work, an unexpected level of excitement about the ROZ fairways emerged. Several companies, intent on exploiting beneath and adjacent to their San Andres fields, began to utilize horizontal drilling and completion strategies that were developed and improved in the unconventional reservoir (aka shale) world. Initial results were very good. In the brownfield situations, it was generally assumed that the horizontally completed well was producing oil from just below the oil/water contact in the conventionally labeled transition zone where some mobile oil was present. But later, two companies began to step out to regions where there was no overlying MPZ and found similar success in what our project had identified as ROZ (Type 3) greenfields. The realization of production in commercial quantities from the greenfields pushes one to acknowledge that it was immobile oil that was being produced since mother nature had already laterally waterflooded the greenfields. The mapping of the greenfield fairways now had a second important commercial justification although not in the original scope of work for the project. The results of this research and introduction to concept of depressuring of the upper ROZ are captured in Chapter 8. Many companies, even those involved, have been slow to realize that the bulk source of this oil being produced in the horizontal wellbores is not coming from the mobile oil component. What the ROZ studies can now show is that the oil must be coming from the residual oil and due to gas expansion as the ROZ is depressured.

One of the questions the investigators faced during the course of the airing of the early ROZ research technology transfer events was whether all of the findings were peculiar to the San Andres formation of the Permian Basin. Fortunately, these questions were foreseen in the formulation phase and a subtask was included in the proposal to examine ROZ potential in the Big Horn Basin of Wyoming and the southern Williston Basin where previous work had shown the presence of hydrodynamic displacement of oil. The researchers suspected both regions to possess Type 3 ROZs. The Enhanced Oil Recovery Institute of the University of Wyoming was encouraged to examine the former and their thorough work looking at the Tensleep formation is summarized in Chapter 8. An internal study by the ROZ team, with late-stage support from the Energy and Environmental Research Center of the University of North Dakota, investigated the latter. The two very brief and scoping efforts have both yielded very positive results confirming the presence of Type 3 ROZs, each of different characteristics than the San Andres ROZs, and are briefly summarized in Chapter 8.

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Chapter 2 – IDENTIFYING, MAPPING AND CHARACTERIZING A MAJOR PERMIAN BASIN ROZ FIELD AND RELATING IT THE REGIONAL SAN ANDRES SETTING

Author: R.Trentham

2.1 GEOLOGIC SETTING AND RESERVOIR PROPERTIES OF THE ROZ AND MPZ.

2.1.1 Introduction

The San Andres Formation is the dominant producing horizon in the Permian Basin, with >10 Billion Barrels of cumulative production from more than 120 reservoirs with >1 Mmbbl cumulative production, and a similar number of reservoirs smaller than 1 Mmbbl cumulative production. The importance of the San Andres Formation for Permian Basin production has been a driver for the numerous studies documenting the stratigraphy, diagenesis, reservoir heterogeneity, and engineering characteristics of this formation. To better understanding the architecture and heterogeneity of San Andres reservoirs, studies of the classic outcrops of the San Andres Formation in the Guadalupe, Sacramento, and San Andres Mountains are looked to as additional sources of data. This overview of the CO_2 flooding potential in the Residual Oil Zones in the San Andres of Goldsmith Field builds on these modern subsurface reservoir studies and outcrop studies.

The San Andres Formation is late Leonardian to mid-Guadalupian (Kungurian-Roadian-Wordian) in age, Figure 2.1, and was deposited as a widespread shallow-water platform associated with the latest Leonardian global eustatic transgressions (Kerans and Ruppel, 1994), across the structural high areas of the Permian Basin. The widespread distribution of San Andres reservoir quality rocks lead to a broad range of reservoir architectures within, and between fields, and the highly variable production.

The basic model of reservoir architecture for the San Andres is that of a carbonate ramp morphing into a rimmed shelf by Grayburg time. The variations in reservoir settings are a function of variations in facies distribution in the ramp interior to ramp crest to outer ramp.

Dutton et al, 2005, have documented a number of play types or “trends” in the San Andres which are the result of complex assortment of depositional, diagenetic and tectonic elements, Figure 2.2. The lower San Andres Slaughter Trend, typified by the Slaughter and Levelland Units in Texas and the Chaveroo and Tom Tom Fields in New

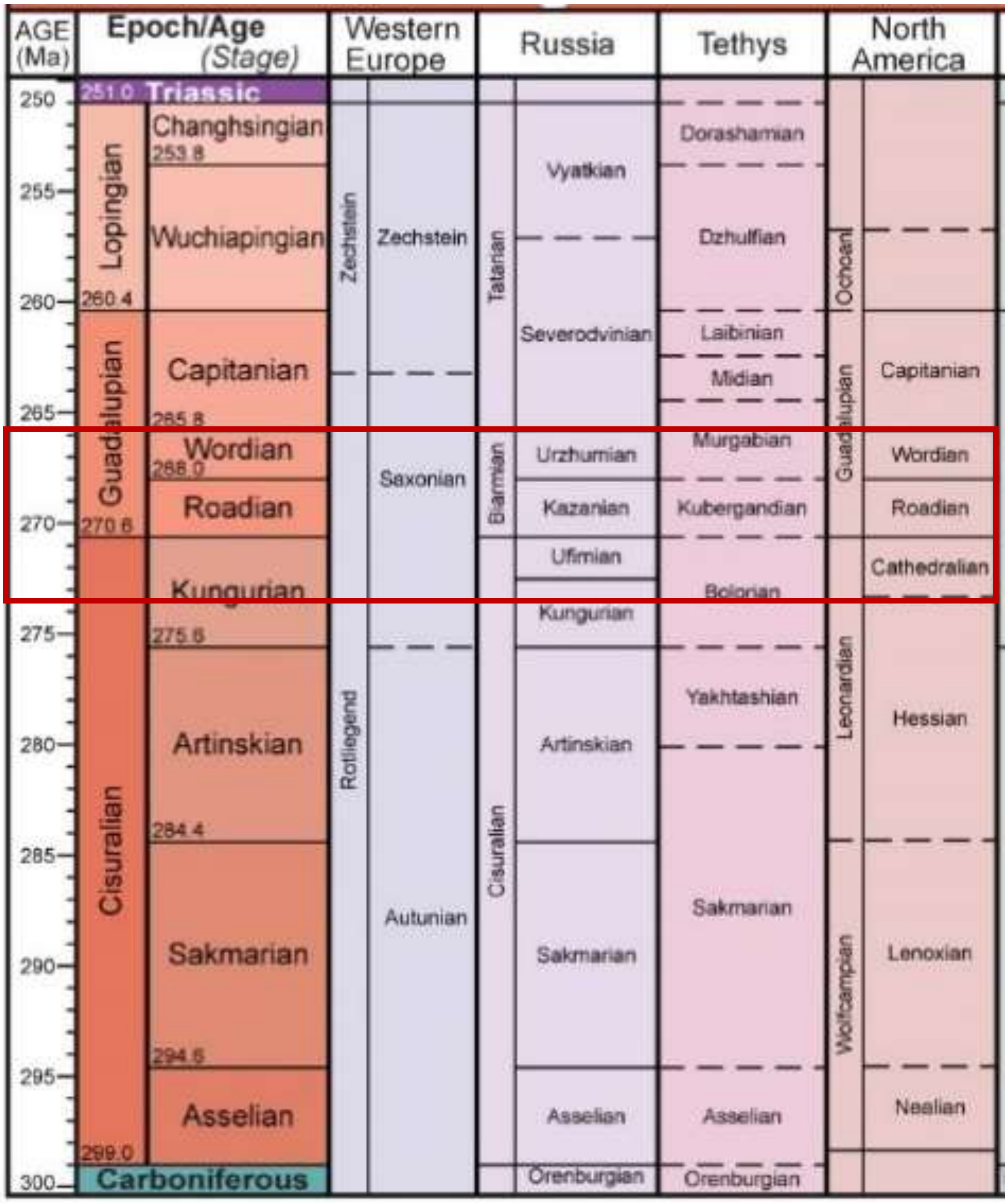


Figure 2.1. Permian Geologic Time Scale. Geologic Time Scale Foundation, 2015.

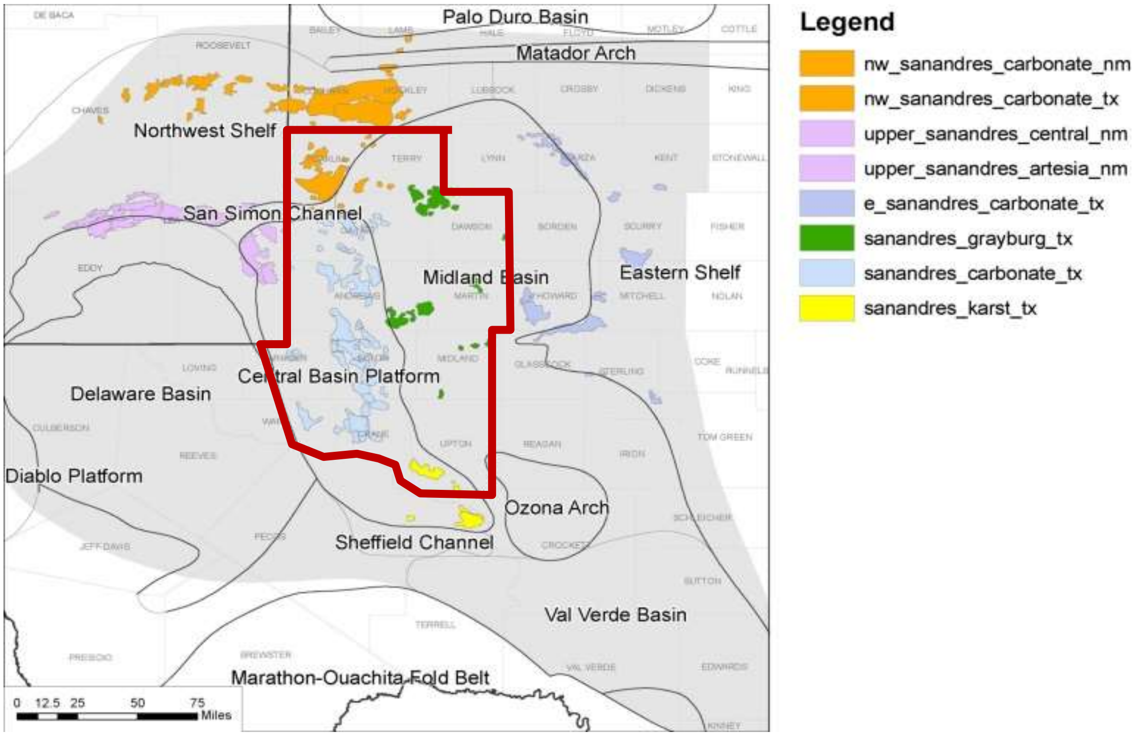


Figure 2.2. Major producing areas and play types or "trends" in the San Andres from Dutton et.al., 2005. 12-County Study outline shown in Red.

Mexico is the most interior (landward) fields, with flat continuous stratification and multiple stacked highstand pay zones separated by intercalated lowstand anhydrite rich sabkhas. The Artesia Trend is the terminal middle to upper San Andres shelf margin along the Northwest

Shelf and western side of the Central Basin Platform, typified by cyclic inner through outer ramp strata, Stoudt and Raines (2000). The Wasson, Seminole, and associated fields (Mathis, 1986; Wang et al., 1996) are also middle to upper San Andres and have thick 200-300 ft pay intervals that have responded well to the full range of primary, secondary, and tertiary (CO_2) recovery methods. Both fields have extensive Residual Oil Zones, >250 to 300' in thickness, which are now being successfully Oil Zones, >250 to 300' in thickness, which are now being successfully exploited with CO_2.

The Residual Oil Zones in this trend, and in Wasson and Seminole Fields, tend to be middle to lower San Andres. Both Fields, with extensive Residual Oil Zones >250 to 300' in thickness

The original 4 County portion of the study, Figure 2.2,, and the expanded 12 County study area, encompassed parts of the Northwest Shelf, Central Basin Platform, and the San Andres Shelves that prograded across the northern Midland Basin. ROZ's are present in all these areas, however, the ROZ's vary in thickness, age, and oil saturations among the three areas.

2.1.2 Previous Work

The San Andres Formation has been studied extensively because of its importance as the dominant reservoir interval in the Permian Basin of Texas/New Mexico. Important early studies on the San Andres Formation outcrop were carried out by Kottlowski et al. (1956) in the San Andres Mountains where the type section is defined, and by Boyd (1958), Hayes (1964), and Kelly (1970), and others, in the more proximal southern Guadalupe Mountains. P. B. King's work in the southern Guadalupe Mountains also contributed greatly to the understanding of the San Andres interval in outcrop. Studies of the regional subsurface by Silver and Todd (1969), Ramondetta (1982), and others, and fusulinid studies by Wilde (1990), and numerous others, form the basis for many modern reservoir studies. The synthesis by Ward et al (1986) of Permian reservoirs and production in the Permian Basin represents the collective knowledge of Gulf Oil's Permian Basin staff and provides an excellent basic reference for studies of the San Andres Formation. Several in-house studies were carried out in the major oil companies (Longacre, 1990; Ward et al., 1986; Purves, 1990, and others), as were a series of reservoir studies by the Bureau of Economic Geology's University Lands Reservoir Characterization program: Bebout et al., (1984); Ruppel and Cander, (1988); Lucia et al, (1992); Major et al, (1990). Although there are a number of studies of the San Andres reservoir on the Central Basin Platform, Bebout & Harris (1986), none discuss the ROZ's specifically. Recent studies of the

Seminole and Goldsmith Fields are amongst the first to concentrate on the “Brownfield” portions of these, or any of the major San Andres reservoirs. These fields have variable Main Pay and ROZ thicknesses where the ROZ’s have responded well to CO2 EOR pilots, and full field development.

The Atlas of Major Texas Oil Reservoirs (Galloway et al, 1982) focused attention on the San Andres reservoirs of the Permian Basin as a major target for future reserve growth. Production in the San Andres is characterized by moderate to low recovery efficiencies of 10-25% of original oil in place (OOIP) during primary production, and much of this has been attributed to bed/cycle scale depositional/stratigraphic heterogeneity and a strong diagenetic overprint that generates variations in permeability (Ruppel and Cander, 1986; Major et al, 1990; Bebout et al., 1984). These same heterogeneities are present in the “Greenfield” ROZ’s. However, recent studies to fewer, homogeneous open marine cycle set packages with heterogeneity in porosity and permeabilty both horizontally and vertically.

These diverse studies of the shallow-water open marine to restricted carbonate ramp model with repetitive facies successions highlighted the high degree of vertical and lateral heterogeneity seen in the San Andres and Grayburg, Ruppel et.al. (1995). Heterogeneities between wells on 10, 20, and 40 acres spacing in these shallow water carbonate ramps is the controlling factor in the relatively low recovery efficiencies. Almost all studies point to these heterogeneities as the primary remaining issue to be resolved in reservoir characterization projects. These studies all note the San Andres reservoir needs to be understood on a case by case basis within a larger stratigraphic context. Beginning in the 1980’s, the San Andres was the first reservoir in the Permian Basin to receive outcrop-based sequence stratigraphic studies, Sarg and Lehman (1986); Sonnenfeld and Cross, (1993); Lucia et al., (1992); Kerans et al., (1993); and Stafleu and Sonnenfeld, (1994). However, it took almost two decades after the introduction of sequence stratigraphy as a reservoir characterization tool, Vail et al (1977), before sequence stratigraphic based models were applied to San Andres reservoirs by smaller to intermediate size companies in legacy major company properties like Goldsmith.

2.1.3 Regional Tectonic Setting

The Permian Basin of Texas and New Mexico is best described as a complex foreland basin that developed during the Ouachita Orogeny beginning in latest Mississippian, continuing thru the Pennsylvanian, and mostly ending during the early Permian (Ye et al, 1996; Ross, 1986). The key structural elements influencing San Andres deposition include the Northwest Shelf, Northern Shelf, Eastern Shelf, and Southern Shelf, San Simon and Sheffield Channels, Central Basin Platform, Delaware, Midland, and Palo Duro Basins, Ozona Arch, Matador Arch, Figure 2.3. The peak of structural activity in the basin was during the Early Permian Wolfcampian, and the direct impact of the structural evolution of the basin has traditionally been believed to have ceased prior to the San Andres time. This is largely based on the outcrop studies in the Guadalupe Mountain, and projected into the subsurface reservoirs on the Northwest Shelf. Though significant fault movement and tectonic rotation diminish through the Early Permian, differential movement and compaction associated with the Ouachita derived tectonic elements influenced facies patterns and reservoir quality throughout the Permian as illustrated in numerous 3D seismic volumes (Sonnenfeld et al 2003; Ruppel and Cander, 1986).

Specific to this project, on the Central Basin Platform, is an area referred to as the “Spine” of the platform, where there is a series of San Andres fields and associated Greenfields, above, and proximal to, the trend of uplifted and heavily eroded lower Paleozoic structures, Figure 2.4. The “Spine of the Platform” is identified by the presence of eroded lower Paleozoic cored blocks beneath the Base of Strawn, Wolfcamp, and/or Leonardian age rocks. The San Andres reservoirs associated with the spine are typically less than 1000’ thick, as opposed to >1300 elsewhere, and are reservoirs where the upper San Andres is missing due to erosion or non-deposition, from Ward, 1992. Although Greenfield areas tend not to be associated directly with the more tectonically active San Andres fields, they are still influenced by the regional tectonics within the Central Basin Platform. The tectonics have not had any significant influence on the Northwest Shelf or the Northern Midland Basin.

Dutton, et.al, 2005, identified 3 “plays” on the Central Basin Platform, Figure 2.5, however, in the Goldsmith Field, and elsewhere on the southern 2/3rds of the Central Basin Platform there is significant variability in the thickness, reservoir distribution, and

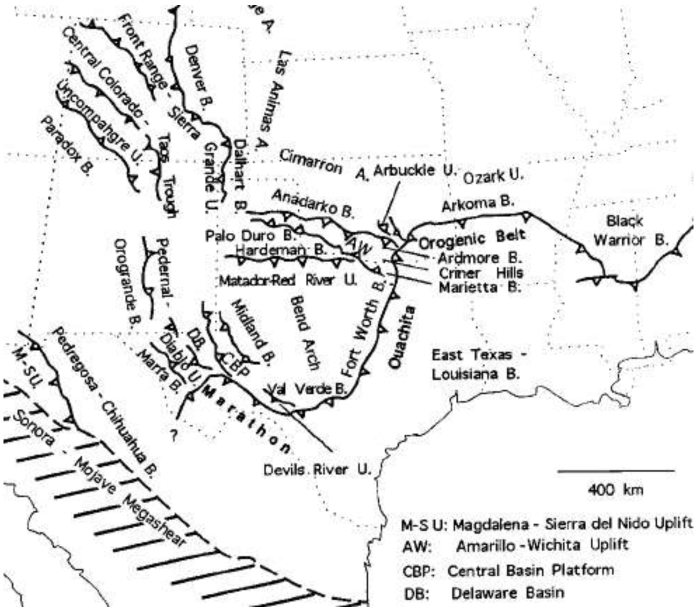


Figure 2.3. Tectonic setting of Permian Basin and Ancestral Rockies. From Ye et al. (1996).

production in the San Andres. These variations can be directly related to flexing of the shallow section associated with periodic movement, at depth, of large structural elements developed during the Pennsylvanian and lower Permian, Figures 2.6 and 2.7. The San Andres varies in thickness on the Central Basin Platform from +/-600' to >1400'. Although some of that variability in thickness is due to the transgression of the eroded Glorieta surface, much of the variation is due to karsting associated with the three eustatic related surfaces within, and at the top of, the San Andres and erosion associated with periodic flexing of the bounding and interior faults of the deep structure elements.

Although there are similarities in the fields in the Slaughter Levelland trend in Texas and New Mexico, and in fields in the Artesia Trend, the San Andres Greenfields on the Central Basin Platform vary and one of the controlling variables is the association with proximity to the Spine of the Platform. In Figure 2.8 (B), a comparison is made of the San Andres isopach (A) with Initial, Production of oil from 1925-1940 wells (C), when many were either competed with nitroglycerine or flowed naturally. There is a strong relationship (B) between areas with high quality reservoir where the well flowed upward of 10,000 BOPD on Initial Potential, in the northeast portion of Ector County, above the Spine of the Plaform. The highest quality wells were not associated with either the thickest San Andres (>1200') or the thinner (<800') San Andres, but with the interval in between where it is proposed that the upper San Andres is absent due to erosion or non-deposition.

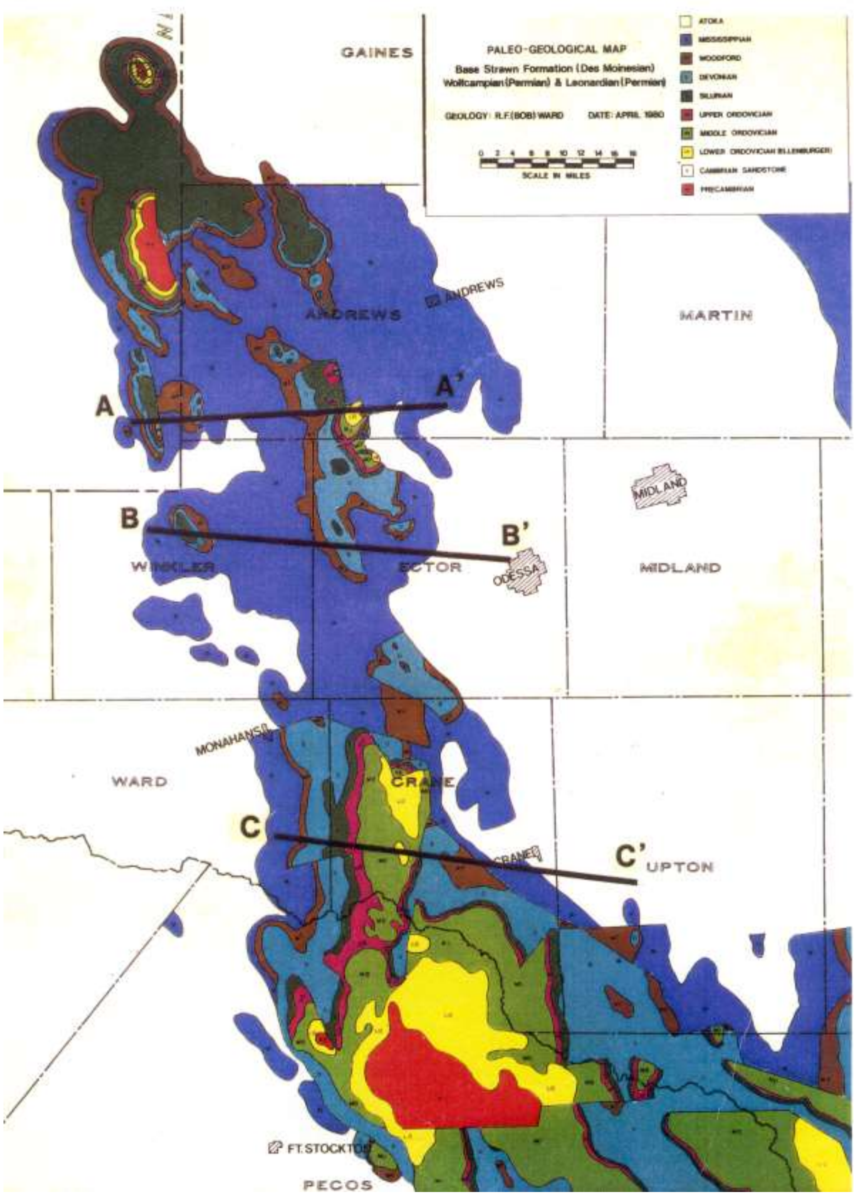


Figure 2.4. The "Spine of the Platform" as identified by the presence of eroded lower Paleozoic units beneath the Base of Strawn, Wolfcamp, and/or Leonardian age rocks. The San Andres reservoirs associated with the spine are typically less than 1000' thick and are reservoirs where the upper San Andres is missing due to erosion. From Ward, 1992.

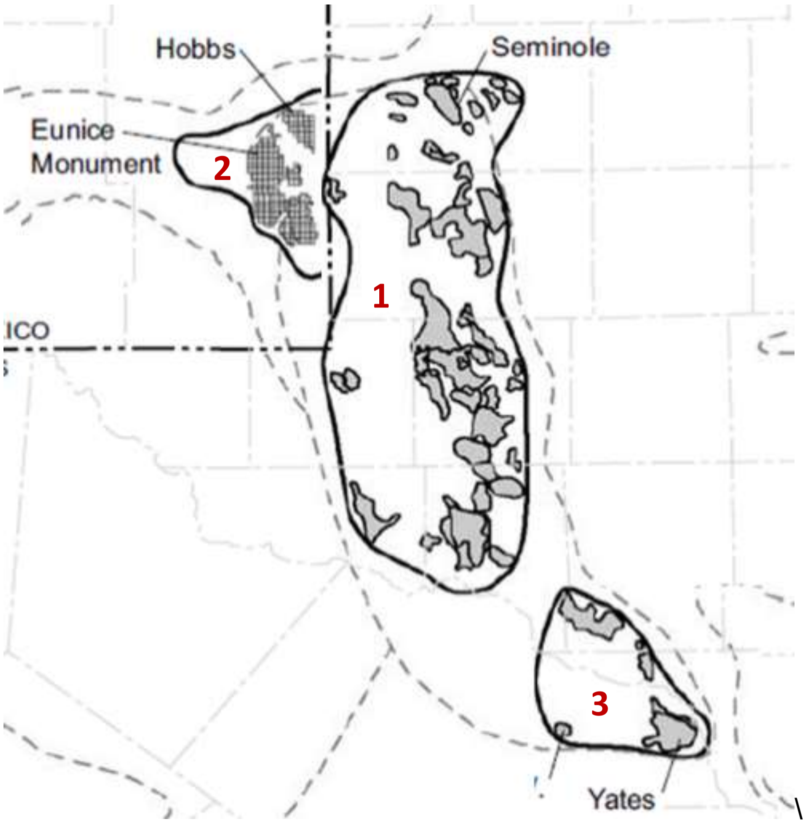


Figure 2.5. San Andres fields on the CBP into the (1) San Andres Platform Carbonate Play, (2) the Upper San Andres and Grayburg Platform Mixed Carbonate Play, and (3) the San Andres Karst-Modified Platform Carbonate Play, Dutton et.al., 2005.

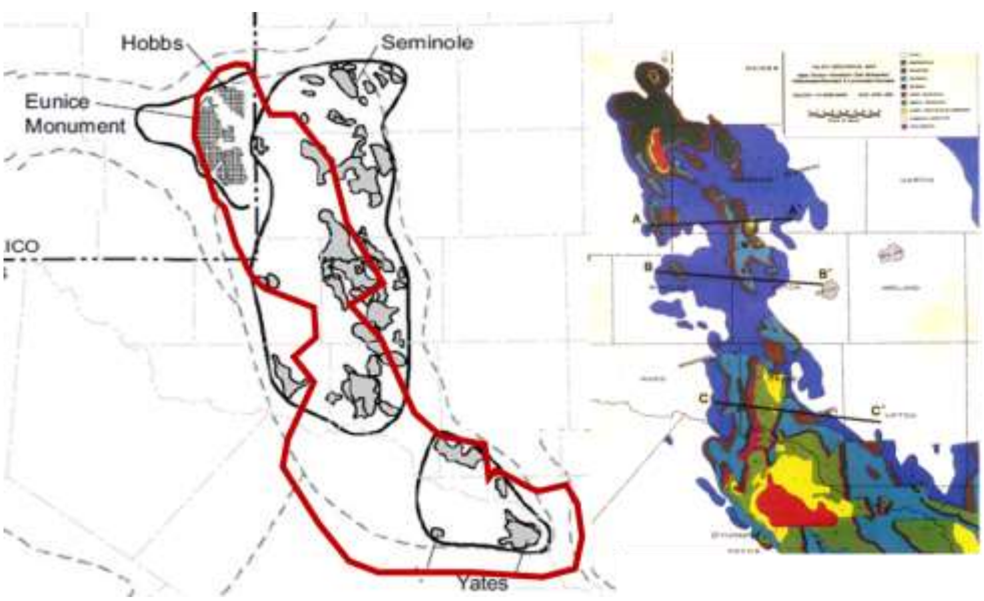


Figure 2.6. Relationship between the "Spine of the Platform" and the three types of plays identified by Dutton, et. Al., 2005. Note that the grouping of the spine related fields transects the play types identified by Dutton.

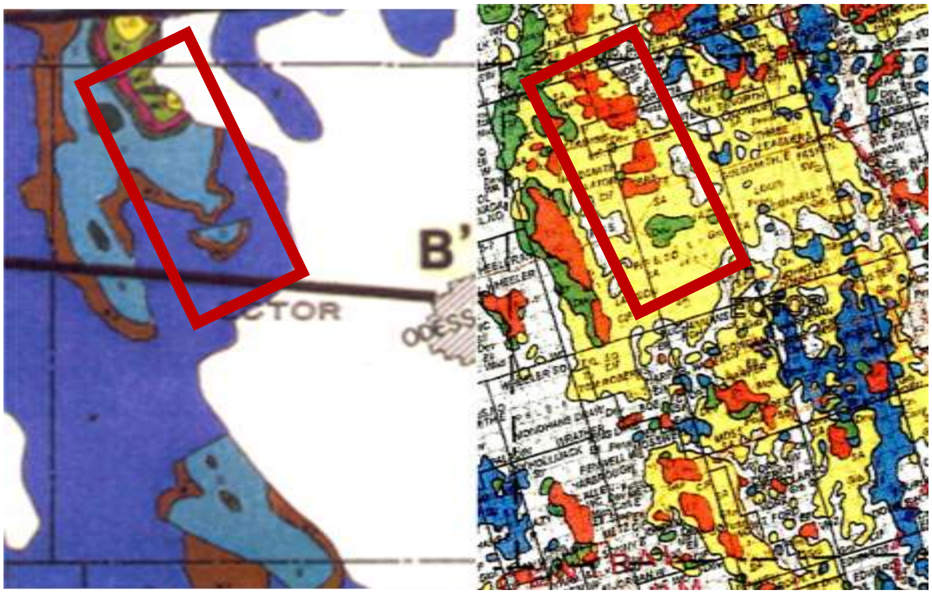


Figure 2.7. Detail from Spine of Platform map (figure 4) showing location of Goldsmith Field relative the deep, lower Paleozoic cored structural elements formed during Permo-Penn.

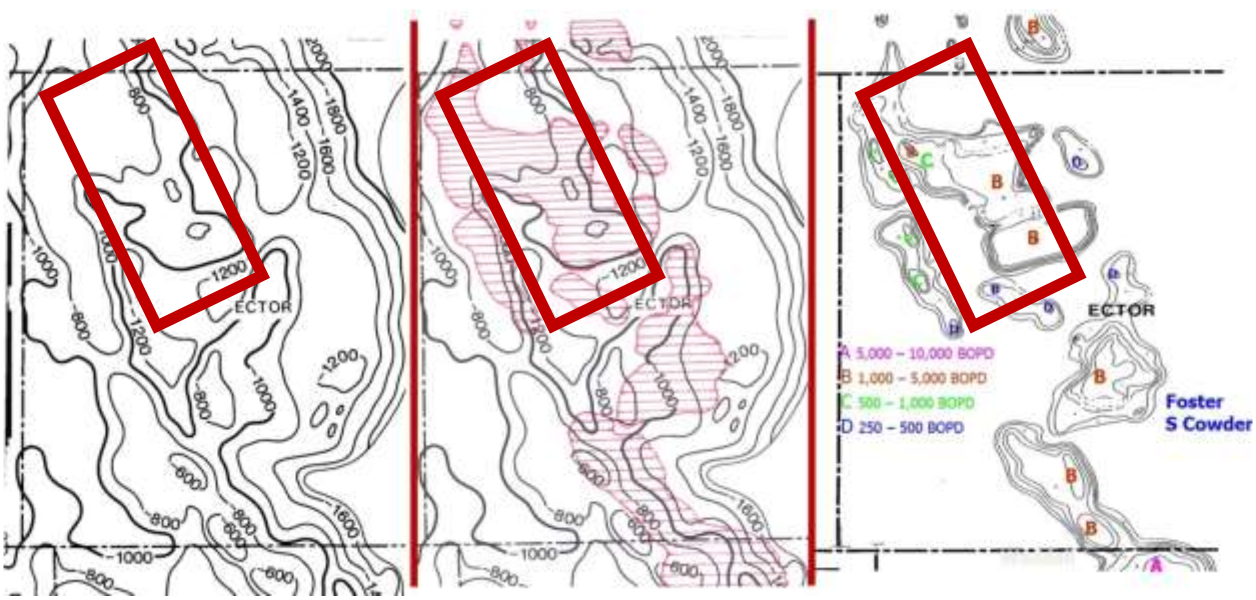


Figure 2.8. Comparison of San Andres isopach (A) with Initial Production of oil from 1925-1940 (C). Note relationship (B) between the thinner <1000' thick San Andres and the higher IP's.

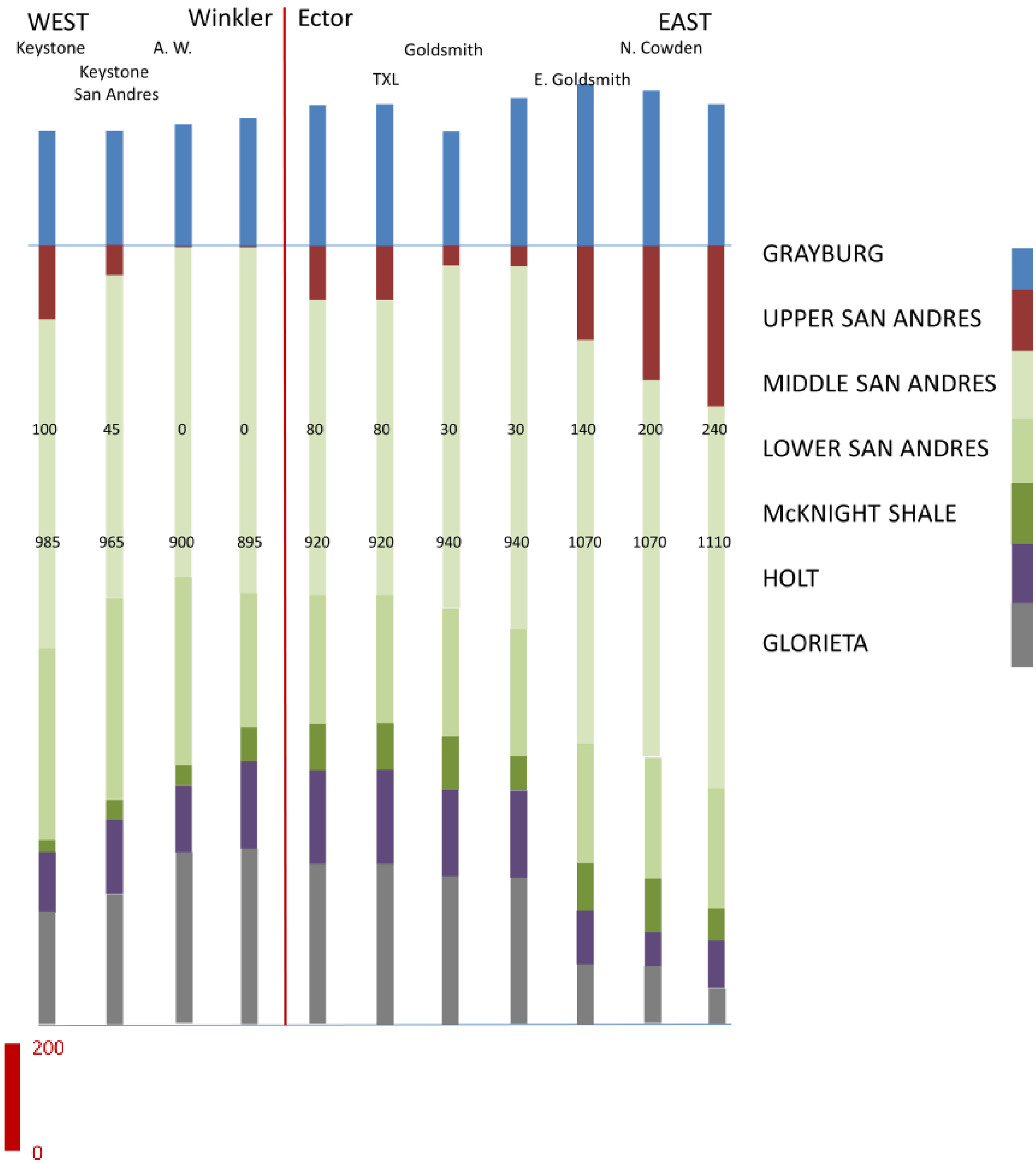


Figure 2.9. Schematic cross section across the Central Basin Platform showing the variability in thickness of the different member within the San Andres. Note that the Upper San Andres varies from 0' in eastern Winkler County to 240' at the east end of the section. Vertical to scale, horizontal not to scale.

This relationship can be seen in the regional east west cross section across section across the Central Basin Platform thru the Goldsmith Field, Figure 2.9. The schematic cross section shows the variability in thickness of the different members within the San Andres. Note that the Upper San Andres varies from zero feet (0') in eastern Winkler County to 240' at the east end of the section. The upper San Andres is estimated to be less than 40' thick in the Goldsmith Field. The Greenfield ROZ's tend to be restricted the deeper, open marine of the middle San Andres.

Historically, It was "common knowledge" that all San Andres fields have similar production and flooding characteristics. This is simply not true as an understanding of the impact of the variation in the upper San Andres and the development of sequence stratigraphic models for the fields demonstrates.

2.1.4 Sequence Boundaries, Paleokarst Surfaces, and erosion in San Andres Reservoirs

Important karst surfaces are developed at the top of the G4, the G8, and the G9, Figure 2.10. Each of these karst surfaces is found developed throughout the Permian Basin and can be marked by solution-collapse features up to 100 ft deep. The top of the G4, equivalent to the Brushy Canyon bypass surface in outcrop and the Pi Marker in the subsurface of the Northwest Shelf, is also shown in outcrop to have a paleokarst profile developed with >10 m thick collapse breccia's. This karst event is equally developed in the subsurface, where its presence has been noted at Vacuum, Raines and Stoudt (2002), and it is also present at the Hobbs San Andres reservoir, Kerans, 2011. Although it is not well developed in core in the Goldsmith Field, it can be correlated in logs across the southern 2/3rds of the Central Basin Platform.

The second karst surface from the outcrop model occurs at the top of the G8, immediately below the Lovington Siltstone marker, a persistent siltstone that can be mapped from the outcrop across the Northwest Shelf at least as far as Wasson, and equivalent to the Cherry Canyon Tongue. This karst event is also widespread and is associated with small (m-scale) sinkholes and fracture systems that likely impact fluid flow in several of the fields, particularly in the NW Shelf mixed San Andres-Grayburg play. The pre-Lovington exposure has resulted in one of the two major erosional events on the southern 2/3rds of the Central Basin Platform (G 8 and G 9). It is typically identified by reddening of the interval below the exposure surface, karst features, and a dirty gamma ray signature in fields such as the McCamey Field, where there is a deeply invasive karst with a pervasive diagenetic overprint. In the Goldsmith Field, the exposure surface is above the top of the producing interval and the surface is masked by the deep erosion associated with the top of the San Andres (G9). Over most of the interior of the Northwest Shelf, the interval is composed of correlative shallow subtidal to intertidal dolomites, some sands and extensive supratidal evaporites. On the Northwest Shelf, there is no evidence of Lovington or post Lovington periods of non-deposition and/or major erosional events.

The top G9 karst event that marks the San Andres-Grayburg boundary is the most widespread and vertically extensive event. This karst surface has been recognized throughout the Permian Basin (French and Kerans, 2004; Stoudt and Raines, 2004; Craig, 1988; Tinker and Mruk, 1998; and Lucia et al, 1992) and is known to have affected reservoir properties in several of the play trends (mainly the Karst-modified San Andres play of Dutton et al., 2005). In the fields associated with the spine of the platform, the event has resulted in extensive erosion or non-deposition. If the top of the San Andres were relatively flat, deep erosion would only be possible at the platform edge. However, the Post Lovington interval is absent, or mostly absent, across the spine area. It is proposed that there may be one or two periods of movement at depth and flexing at the surface during and/or at the end of the upper San Andres. This would have resulted in significant reduction in the thickness of the upper San Andes interval thru non-deposition and erosion.

	Guad Mts.	Downdip Northwest Shelf	Updip Northwest Shelf NM	TX	Delaware Basin	Central Basin Platform	Eastern Shelf, NE Midland Basin
	Guad. 10	Grayburg 1 Premier Sand	Evaporites		U. Cherry Cnyn	L. Grayburg	L. Grayburg
Upper San Andres Composite Seq. CS10	Guad. 9	Upper S A Lovington Sand	Evaporites		L. Cherry Cnyn	U. San Andres Lovington Sand	
	Guad. 8	Upper S A	P1-3	Slaughter 1-3		U. San Andres	U. San Andres Cedar Lake, Welch
	Guad. 7				Brushy Canyon		
	Guad. 6						
	Guad. 5						
Lower San Andres Composite Seq. CS9	Guad. 4	Upper S A2	P4	Slaughter 4	U. Bone Spring or Cut Off	San Andres	San Andres
	Guad. 3	Upper S A 1	P5	Slaughter 5		San Andres	
	Guad. 2	Middle S A2	P6			McKnight Shale	
	Guad. 1	Middle S A 1	P7				
	Leonardian 8	Lower S A 2	P8			Holt	Lower San Andres Howard Glasscock, Iatan, Ddiamond M
	Leonardian 7	Lower S A 1	P8		Pipeline Sh		
	Leonardian 6	Glorieta	Glorieta		Bone Spring	Glorieta	San Angelo

Figure 2.10. Stratigraphic Terminology, Kerans, 2006, Modified after Kerans, 2000, Trentham and Smith, 2002.

The Upper San Andres (G9), Lovington sand and Carbonate is present across the Northwest Shelf. Over most of the interior of the shelf, it is composed of correlative shallow subtidal to intertidal dolomites, some sands and extensive supratidal evaporites. On the Northwest Shelf, there is no evidence of Lovington or post Lovington periods of non-deposition and/or major erosional events.

2.1.5 Distribution of the Residual Oil in the ROZ

2.1.5.1 Goldsmith Field Stratigraphy

Since the early geological models of the field, the reservoir has been characterized as being composed of a shallowing upward Open Shelf, - Shallow Shelf -Shoal to Tidal Flat sequence, Figure 2.11. The ROZ is composed primarily of Open Shelf Fusulinid Packstones and Wackestone. However to better understand the reservoir and to provide a sequence stratigraphic based model for the history match and reservoir simulation, a more detailed picture of the San Andres was necessary.

The San Angelo, referred to as the Glorieta in New Mexico and on the Northern Central Basin Platform, is uppermost Leonardian in age and has been identified as “L6” in the widely accepted update of the sequence stratigraphy of the Permian Basin (Kerans, 2006). At Goldsmith, Figure 2.12, it is a dense, hard, microcrystalline to sucrosic, tan to brown, dolomite. There is abundant nodular and intercrystalline anhydrite and some thin bedded, green, fissile dolomitic shale. There is minor production from the interval on the flanks of the south dome on the Goldsmith San Andres Unit leases south of SH 158 where it is referred to as the “Holt Pay”. Shows and production are associated with intercrystalline and relatively fine solution vuggy porosity. The interval is also productive in the East Goldsmith Field and has been considered as a target for CO_2 EOR there. In the Goldsmith San Andres Unit leases south of SH 158, production from the upper San Angelo “Holt” and lower San Angelo “Lawson Simpson” pay has been reported as included in the “5600” pay.

In Ector County there is some confusion as to the “pay name” Holt and its position in the section. The original “Holt: pay was a deeper, lower San Andres pay zone identified in the Gulf #1 Holt, Section 1, Block A, PSL, in northcentral Ector County. However, in the Keystone Field 30 miles to the west in Winkler County, the “Holt Pay” is not stratigraphically equivalent to the North Cowden pay zone but is San Angelo in age. The Holt Pay referenced above is also not stratigraphically equivalent to Holt elsewhere. The “Holt” is considered to the stratigraphic equivalent of the Shumard with abundant brachiopods, bryozoans, corals, and fusulinids. The L8 represents a continued backstepping and deepening relative to the underlying L7. The overlying McKnight Shale represents the maximum flood on the interior of the Central Basin Platform, Figure 2.12.

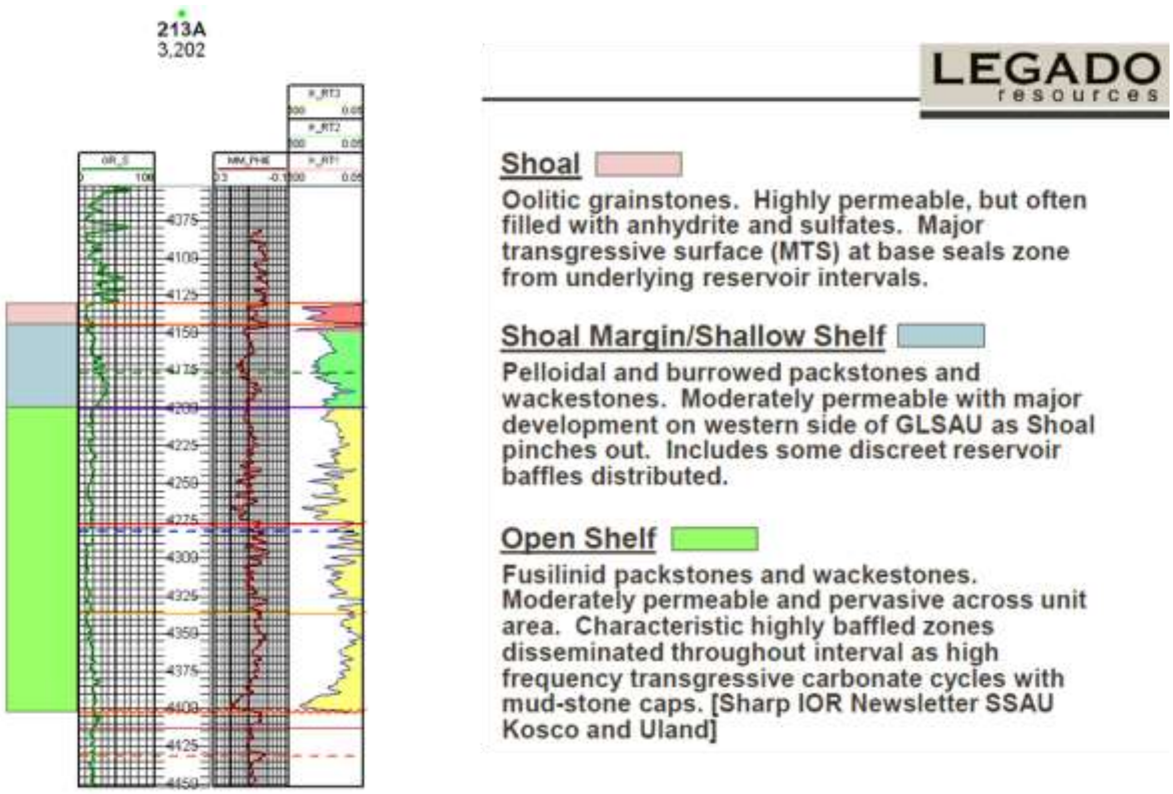


Figure 2.11. "Classic" interpretation of the depositional environments in the Goldsmith Field. Legado, 2013.

In the Goldsmith Landreth San Andres Unit (GLSAU), the Holt is upper Leonardian, L7 and L8, and rests uncomfortably on the San Angelo, Figure 2.13. The L7 and L8 interval are distinct with a minor gamma ray signature separating the L7 from L8. They are sugary, dense, cherty, anhydritic and glauconitic limestone and dolomite. The interval is locally referred to as "McKnight" but this designation is more properly used to identify the McKnight Member of the Cutoff Formation in the Delaware Basin. The L7 interval is composed of a rapidly deepening open marine wackestone to packstones with shale (G1 – G2 from Kerans) above the Holt, and the limestone interval above the McKnight shale as (G3). The dolomite portion is porous and productive in the area, with shows in the Goldsmith and East Goldsmith fields. The interval is known for

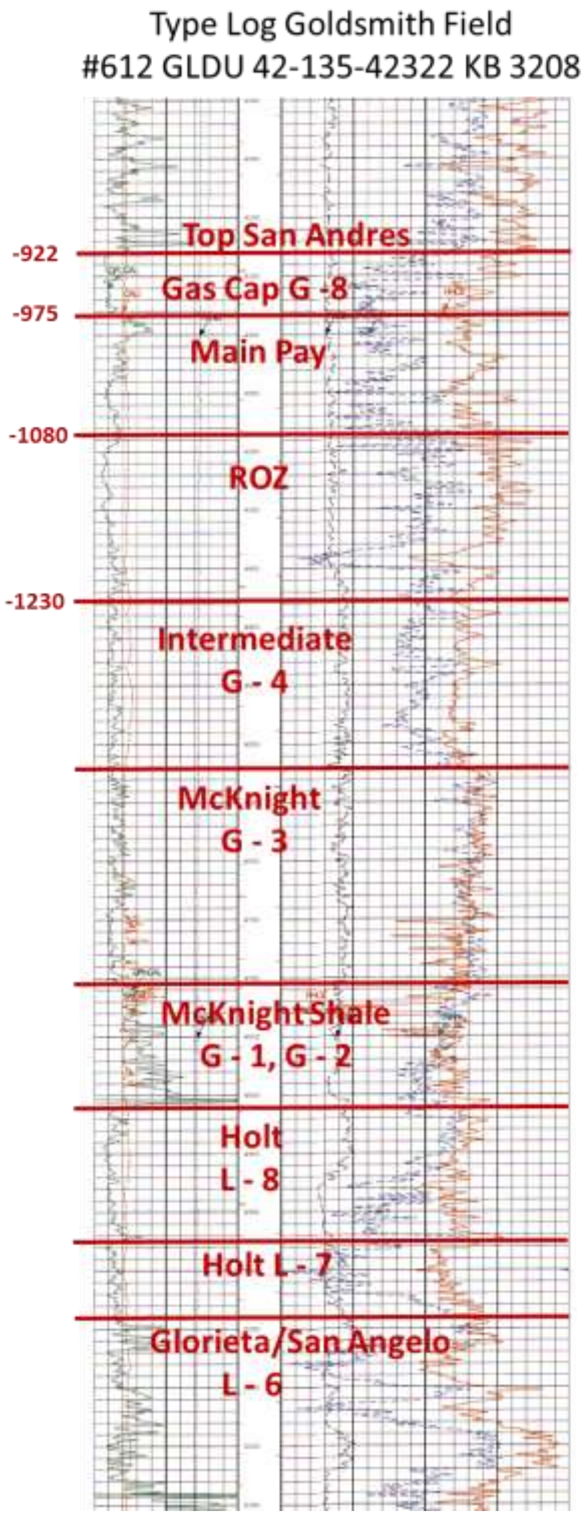


Figure 2.12. San Andres Type Log, Goldsmith Field. The G9 is missing due to non-deposition or erosion.

producing “sour” or sulfide-rich water. This suggests the interval has been swept by last stage meteoric derived waters due to processes described in Chapter 4. Elsewhere on the platform, the rapidly deepening L7 is referred to as the “Dense Zone” as it typically is a dolomite lacking porosity.

The McKnight Shale, Figure 2.12, which rests on the L8 limestone without an apparent hiatus, is considered to be lowermost Guadalupian, G1 – G2. The McKnight Shale is a high gamma ray, shaley, dark brown, dense, hard and cherty limestone. The easily correlatable shale is restricted to portions of Ector and Andrews Counties. However, it can be correlated across the Central Basin Platform with some difficulty. It is proposed to be the Maximum flood of the lower San Andres transgressive sequence and would be correlated to the El Centro member of the Cutoff Shale in the Delaware Basin and the “P4”member of the lower San Andres on the NW Shelf, Gratton & LeMay, (1969). The deeper water P4 limestone interval extends furthest north of all the lower San Andres intervals on the northwest shelf and is considered to represent the maximum flood of the lower San Andres and be equivalent to the El Centro Member of the Cutoff. The McKnight Shale in the pilot area is at an approximate depth of 4850 to 4900’.

The interval above the McKnight Shale is called the “McKnight” pay in Crane County (G3). This limestone is sugary, dense, buff to brown, and cherty with abundant interstitial anhydrite. It typically lacks significant porosity. This interval elsewhere has been described as being deposited on a deep shelf with abundant crinoids, brachiopods, and bryozoans. Chert nodules, often focused around skeletal grains, are abundant. This interval has no associated production or significant reported shows in the Goldsmith area, but on the west side of the Central Basin Platform, where it has been dolomitized, it has produced minor amounts of oil in scattered wells. The McKnight in the pilot area is at an approximate depth of 4500 – 4850’.

The productive carbonates in the Slaughter-Levelland trend are believed to be G3-G4 (?) sequences, with the underlying San Andres limestones being the equivalents of the L8, G1, and G2. The G1-4 model/facies assemblage as observed along the

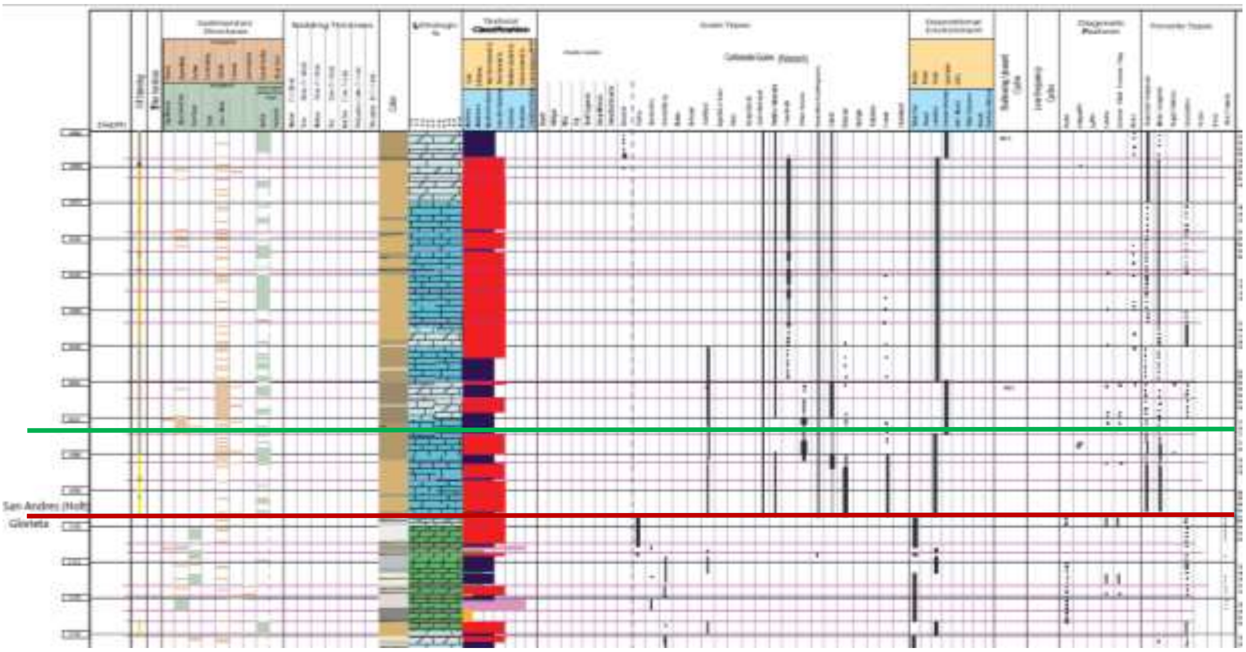


Figure 2.13. Core Description of Lower San Andres "Holt" from East Goldsmith Field. Red line is top Glorieta/Base Holt. Green line estimated to be top L7. Top of L8 is +/-10' above top of core. Both intervals are interpreted to be open marine (Red boxes) and deeper open marine (dark blue boxes).

Algerita Escarpment is the best analog for the Northwest Shelf San Andres Platform carbonate and the San Andres platform carbonate play of Dutton et al (2005).

The interval immediately above the McKnight Limestone (probably G4) between the McKnight and the Judkins has been designated as the "Intermediate Zone" in Crane and Ward Counties and the Lower "Judkins" (G4) in the Goldsmith Field. The interval is below the ROZ and is dominantly composed of fusulinid wackestones to packstones deposited in an open marine environment. The interval is predominantly limestone at the base with variable percentages of euhedral, fabric selective dolomites crystals increasing upward, ranging from 20 to 80% of the matrix only. There is 5 to 15% porosity in the matrix and intraskeletal porosity in the fusulinids. The variable amount of dolomite leads to a suppressed dolomite neutron-density log signature (on limestone matrix log) and a PE signature that falls between dolomite and limestone (~4.0). In core the fusulinids and other skeletal grains are well preserved and yield an active reaction to HCL. At the top of the interval, picked as the base of the ROZ, the fusulinids are either replaced with anhydrite or are leached. This transition is abrupt, typically occurring across a few inches to feet. Although there can be some oil stain in the “limestone” interval, there is a significant increase in stain visible above the transition.

The “Judkins Dolomite” (G8), the upper of two producing intervals in the San Hills Field in central Crane County where the pay name Judkins originates, is one of the major producing intervals basinwide in the San Andres. The Judkins (G8) is represented at Goldsmith by the Residual Oil Zone and Main Pay and is often referred to as Lower San Andres in the older field descriptions of the interval on the Central Basin Platform, in the Vacuum Field, and in other fields on the northwest shelf. The interval is commonly gray to brown, micro-crystalline to sugary dolomite, and contains nodular and interstitial anhydrite and crystals of gypsum. Scattered re-cemented vertical fractures and numerous stylolitic shale partings are present, the porosity is principally of a secondary nature and consists of solution vugs and fusulinid cast types. Pays are distributed across the field and in portions of the TXL-Goldsmith saddle area. There is a “Shoal” in the upper portion of the Main Pay which is composed of light tan, hard, oolitic grainstone in upper part, which is the top of commercial oi bearing porosities in the Judkins. In ascending depth order, major depositional units of the ROZ and Main Pay included bryozoan/sponge/pelmatozoan wackestones and packstones, fusulinid/peloid pack/grainstones, ooid/peloid pack/grainstones, and tidal flat capped cycles. A probable third order sequence boundary, marked by deposition of the Lovington Sand **(**Stoudt & Raines, 2000) , identified as a major sequence boundary in the San Andres formation on the Algerita Escarpment represents the top of the San Andres pay in the field.

The upper San Andres Lovington Sand and post Lovington Carbonates are not identified at Goldsmith. There is an interval between 4085 and 4130’ in the #612 GLDU, Figure 2.12, which may be G9 or lower Grayburg. In the Foster Field, the transition between the upper San Amdres (G 9) and the lower Grayburg is unclear. In areas where the Premier Sand is present at the base of the Grayburg the boundary is clear. That is not the case at Goldsmith Field.

2.1.5.2 Core Based Sequence Stratigraphy – Based on Study of Goldsmith Landreth San Andres Unit (GLSAU)

Nine (9) wells, Figure 2.14, were cored as part of the Goldsmith Landreth San Andres Unit study, Trentham, ET. Al., 2015, to make a complete sequence stratigraphic model of the reservoir. During the waterflood development of the field, a number of cores were recovered from the Main Pay Zone and Gas Cap.

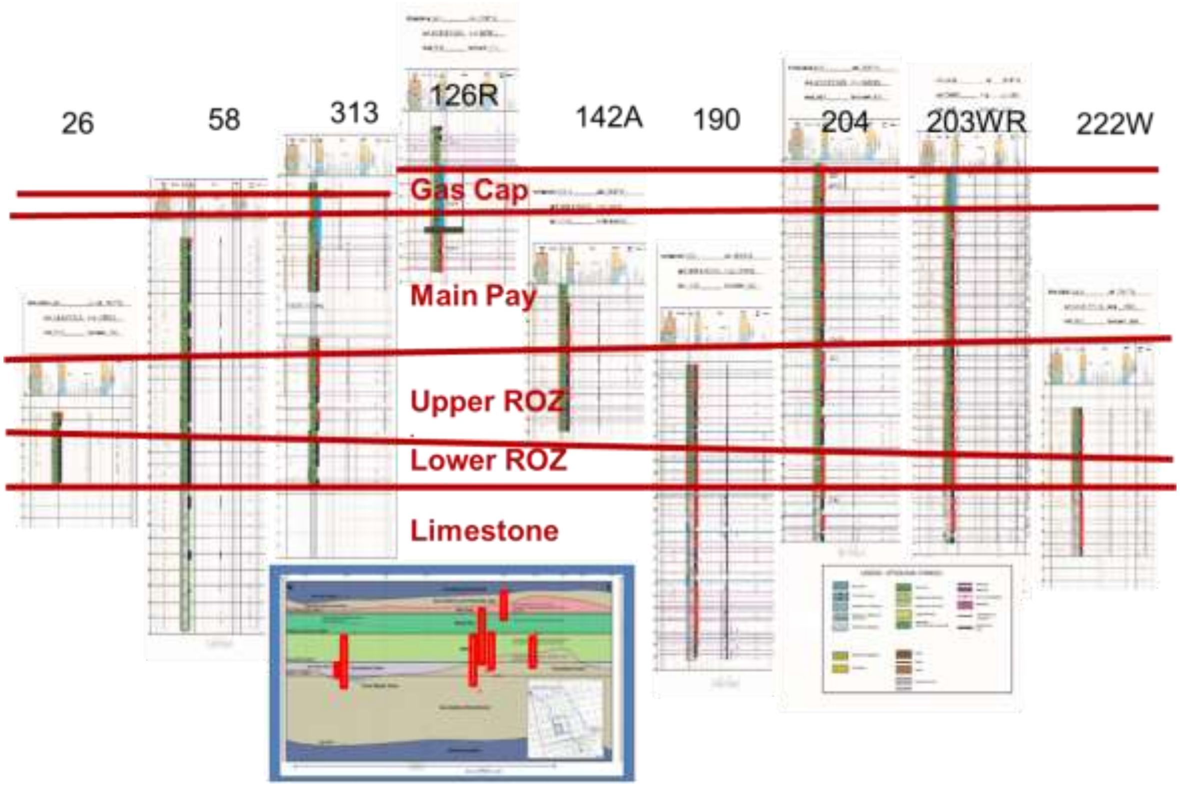


Figure 2.14. Small scale, Northwest to southeast core cross section of the 9 cored wells in the study.

However, there were no cored recovered from the ROZ or the limestone below the ROZ during that time frame. For the first time, therefore, the ROZ and the limestone interval below the ROZ were purposely cored. This was in order to generate a data set of oil and water saturations, porosities and permeabilities of the ROZ for comparison to the waterflooded main pay, determine the facies, sequence stratigraphy, and diagenesis of the ROZ, and provide data to compare to the saturations calculated using open hole logs. Cores were also recovered from the Main Pay and Gas Cap to determine the residual to waterflood saturations for comparison with the saturations in the ROZ.

Legado, compared the oil saturations in the Main Pay and ROZ and determined that the residual to waterflood saturations were similar to the saturations in the ROZ which are the result of Mother Nature's Waterflood. Figure 2.15 is a comparison of oil

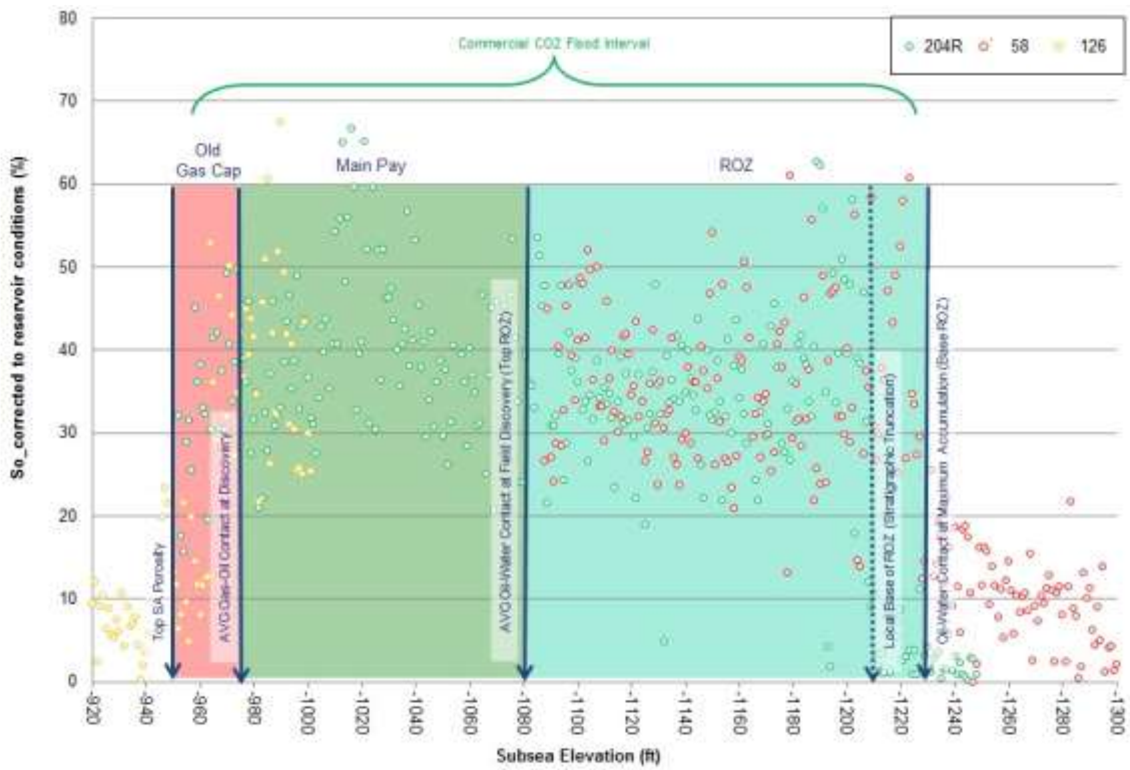


Figure 2.15. Comparison of oil saturations from the #204 W, #126, and #58 GLSAU cored wells. Note that the saturations from the Main Pay (residual to waterflood) and the ROZ are almost identical. The Gas Cap has oil saturation as a result of having been resaturated during the waterflood. The saturations decrease rapidly below the ROZ indicting the presence of the Paleo Oil/Water contact at that depth. Legado, 2013.

saturations from the #204 W, #126, and #58 GLSAU cored wells. Note that the saturations from the Main Pay (residual to waterflood) and the ROZ are almost identical.

The Gas Cap has oil saturation as a result of having been resaturated during the waterflood. The saturations decrease rapidly below the ROZ indicting the presence of the Paleo Oil/Water contact at that depth. This was found to be consistent with the other cored well recovered during this study. It is also consistent with work done by Hess at Seminole Field where similar values for saturations in the ROZ were determined.

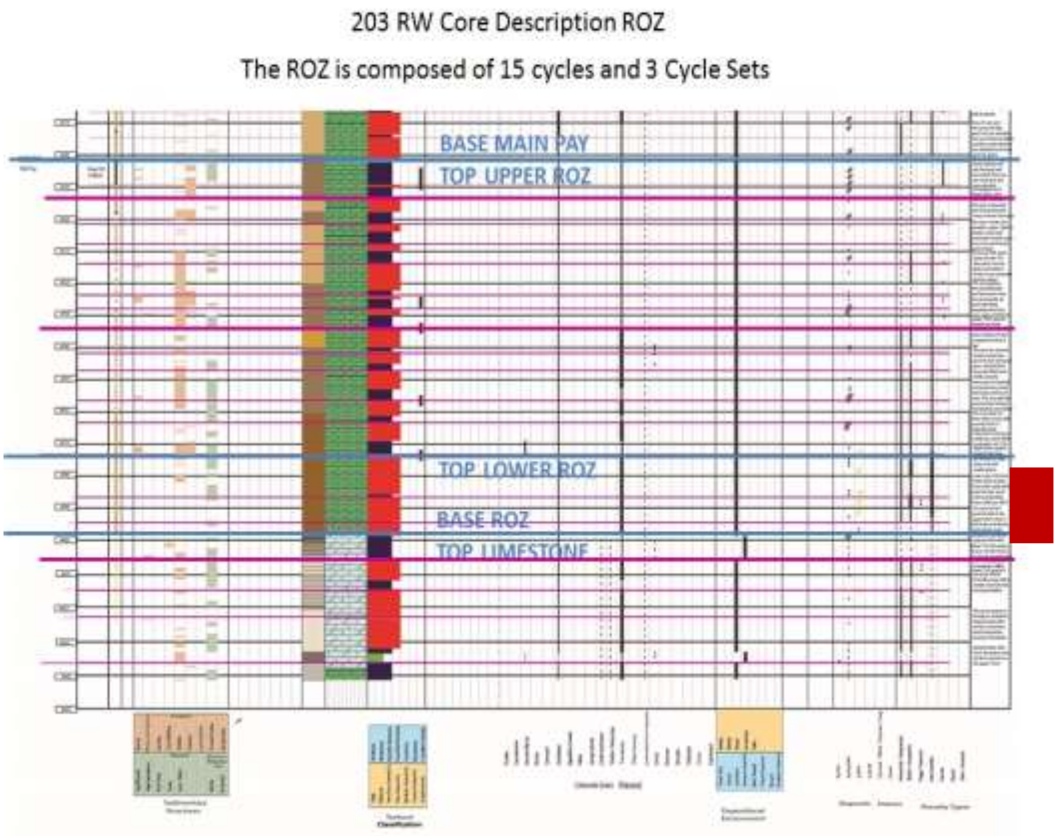


Figure 2.16.Goldsmith Landreth San Andres Unit #203RW core description. The heavy red bar on the right is the interval with increased saturation, believed to be in the CO_2 flood related oil bank. Thin red lines are Cycle boundaries, thicker red lines are Cycle Set boundaries.

The cored wells form a roughly northwest to southeast cross section across the Goldsmith Landreth San Andres Unit. Each of the cores were described by the geologic team and matched to the open hole logs run in the cored wells. The cores were examined to identify individual cycles and cycle sets, and the flow units present in the reservoir. The generation of flow units was essential in guiding the history match and reservoir characterization. The identification of a lower and upper ROZ in the cores allowed for a rock based interpretation of the injection profiles.

The cores were critical to the understanding of the reservoir. Oil response in the GLSAU #203 RW was excellent and very rapid in the pilot and, early in the injection history, it was necessary to plug back from the fast processing lower unit of the ROZ (LROZ), and concentrate the injection in the upper member of the ROZ (UROZ), Figure 2.16. The operator's most desirable solution was to replace the original well (#203W) and drill and core a replacement well (#203 RW). The new well was drilled ~135' from the original well, just outside the original pattern (see Figure 2.17 below). Both the MP and ROZ were cored and it became apparent that there were elevated oil saturations (So) in the LROZ when compared to other cores taken before the inception of the CO2 flood. These

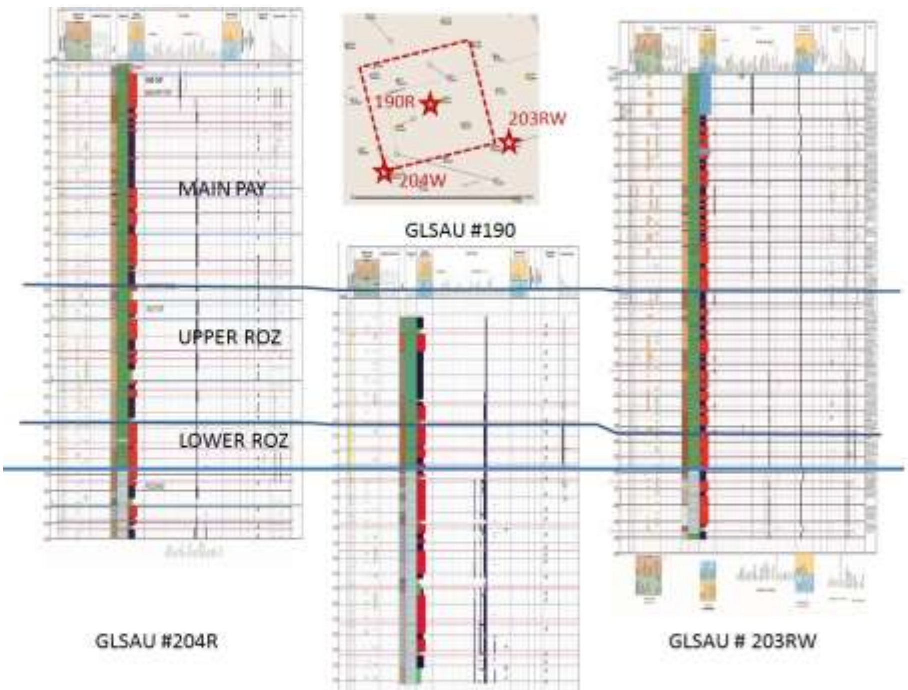


Figure 2.17 Pilot pattern and cores from pilot wells. Correlations of Main Pay, Upper and Lower ROZ is consistent across the field.

elevated So values just outside the pilot pattern serves as proof of oil 'bank' development in LROZ that had provided the fast response inside the pattern and was caught in the act just outside the pilot pattern. As CO2 had been injected in the lower ROZ for a brief period, the flood front had advanced to the center producer but not moved far beyond the location of the replacement well (#203 RW) outside the injector. The evaluation of the saturations, and the presence of CO2 in the core when it was first recovered from the core sleve, confirms the decision to divide the ROZ into a Lower and Upper members, Figure 2,17.

Sulfur was believed to be present in the reservoir based on limited data from a number of other ROZs. This was confirmed by the presence of native sulfur crystals immediately above the base of the ROZ. The sulfur is found as fractures and fusulinid molds, and in vugs associated with calcite and anhydrite. The presence of sulfur is believed to be associated with Mother Nature's Waterflood and the activity of anerobic bacteria.

2.1.6 Develop a Geologic Model for the ROZ

2.1.6.1 Cycles, Cycle Sets, and Flow Units.

The question: why is the ROZ swept by Mother Nature's Waterflood and the Main Pay not? The geologic answer is that the ROZ in most fields, and in the Goldsmith Field in particular, is composed of thicker, open marine cycles than the main pay, have fewer baffles and barriers to flow, have slightly higher average porosity and permeability, less karst, and simply swept better than the main pay interval. Multiple thick, open marine cycles are seen in all the cores taken from the ROZ and the mixed dolomite and limestone interval below the ROZ. Also as noted above, these cycles have muddy bases and grainy tops. In the ROZ in the pilot area, there are two packages, the lower and upper, that have higher percentages of grainy tops, and a central interval that is primarily mud rich. This creates two flow units within the ROZ which have had an influence on sweep efficiency. The lower unit has slightly higher permeability and porosity, and thicker open marine cycles, although it is composed of the same lithologies as the upper ROZ.

Numerous karst features are seen, primarily in the MPZ, but also in the ROZ to a lesser extent, which are comparable to similar features seen on outcrop. They include dissolution, cave development, vertical solution pipes, and collapse structures. Sandstone infiltration present on the northwest shelf and the northern Central Basin Platform is not present at the Goldsmith Field as the upper San Andres/lower Grayburg aeolian sands had not progressed past the northern 1/3rd of the platform at this time.

Tidal flat capped cycles widespread in the MPZ but are not present in the ROZ. These cycles have low permeability, and function as local vertical and lateral barriers to flow. Use of the outcrop analog enables prediction of the 3-dimensional distribution of tight cycles and their impact on reservoir continuity.

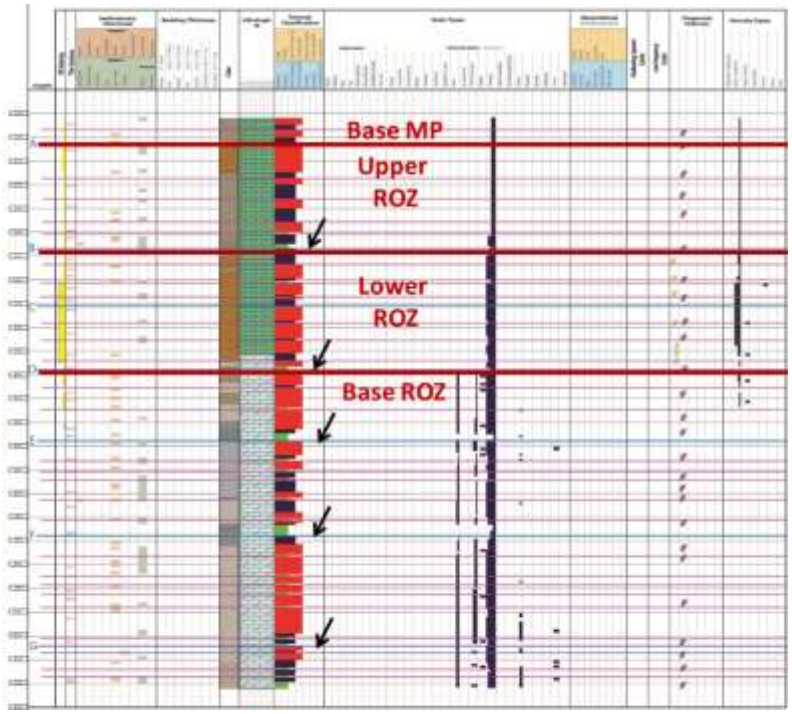


Figure 2.18. Detailed Core Description of the GLSAU #190 Well, Goldsmith Landreth Unit, Ector County, Texas. Note well developed maximum flooding surfaces marked with black arrows.

Below the ROZ, in the G4, or “Intermediate Zone”, the core is a partially dolomitized fusulinid/crinoid/ brachiopod wackestone to grain dominated packstone. Dolomite is largely confined to the rock “matrix”, grains are calcitic, resulting in a “limestone” log signature. Only 5 of the 9 studied cores penetrated significant intervals of the mixed limestone/dolomite interval (G4) below the ROZ, and none penetrate the McKnight (G3). The #190 and the #58 both penetrate almost the entire interval. The #190, Figure 2.18, which is one of the injection wells in the original 5 spot CO_2 injection pilot, is higher structurally and is immediately above the deep seated, lower Paleozoic cored uplift, whereas the #58 is off the flank of that deep structure and in a lower area at the top of the San Andres, Figure 2.19. The #58 is composed primarily of wackestones. In the lower “limestone” interval with 20% mud-rich packstones, the fusulinids, brachiopods and corals are representative of a deeper water open marine environment. The #190, is composed of grain-rich packstones with minor mud-rich packstones and wackestones. This indicates a higher energy open marine environment, suggesting that the #190 was on a paleotopographic higher area than the #59, Figure 2.19. The penetrations of the mixed limestone/dolomite in the #204R, #203RW, and #222W all have similar percentages below the base of the ROZ is not 100% limestone and contains up to 80% dolomite in the matrix. The lower and Upper ROZ flow units are defined by the fusulinid brachiopod grain-rich packstones (stacked red blocks) and are separated by the wackestones to mud-rich packstones (dark blue boxes).

of grain-rich packstones with minor mud-rich packstones and wackestones. All these wells are also above the deep-seated structural high suggesting the presence of a paleotopographic high at the location of the original 5 spot CO_2 injection pilot, and the surrounding southern portion of the study area. Porosity in this interval is intercrystalline and moldic, averages 10-12%, but contains only water. The internal fusulinids are perfectly preserved in this interval, as are the other fossils and all fossils are 100% calcite. There are small, euhedral dolomite rhombs throughout the matrix of the limestone. The percentages of dolomite in the matrix range from 20 to 80%. There is good to excellent intercrystalline and intragranular porosity in most of the interval. Figure 2.20 is a comparison of (A) Limestone below ROZ with small euhedral dolomite crystals (white crystals) and fusulinids with preserved internal structure, #204 W GLSAU, depth 4445.85, with (B) subhedral to anhedral dolomite with fusulinids replaced with anhydrite from ROZ, depth 4326.25'. This is typical of the rapid changes in mineralogy seen in all the cores. Because of the small size (>.1mm) and the non-fabric destructive aspect of the dolomite it is believed the dolomite was deposited early by brines moving thru the sediments.

The #58 is also the only core where there is a considerable amount of chert. It is suspected that this indicated that the #58 was in the furthest down structure position as the chert is typically found in the deepest water environment in an area.

Depositional cycle boundaries are difficult to pick in most of the fusulinid wackestone to grain dominated packstone intervals. However at least two significant dark brown, mudstone to wackestone cycle bases were identified below the ROZ. Although these have no impact on reservoir quality, sweep efficiency, or production, however, these can be carried across the Landreth Unit and help in establishing the extent of baffles to vertical flow when inserted into the reservoir model.

The lower ROZ interval rests immediately on the top of the mixed limestone/dolomite interval. The transition between small fabric selective euhedral dolomite crystals in the limestone matrix only to larger subhedral to anhedral fabric destructive crystals with the fusulinids replaced with anhydrite or dissolved occurs within inches to a foot or two in all the cores which penetrated the transition.

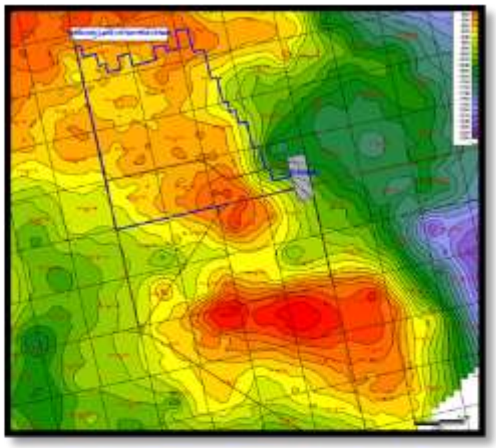


Figure 2.19. Relative Structural position of the #58 and #190 GLSAU. Top San Andres Structure of Goldsmith Field. The Goldsmith Landreth San Andres Unit is outlined in blue in the northwest portion of the field. Legado, 2011.

Lithologies in the ROZ are also fusulinid/crinoidal wackestone to packstone, but they are 90-95% dolomite, with traces of calcite cement or remnant crinoid grains and anhydrite. Fusulinids have been leached, resulting in moldic porosity, Figure 2.18.

The GLSAU #204 well was cored down to below the base of the ROZ. Lithologies are fusulinid wackestones to packstones, but very little limestone remains. Cycle bases are more micritic, cycle tops are grainy. Porosity is intercrystalline and moldic, averages 10-12%, with primarily water in the pores. There is no difference in rock type between the main pay and the ROZ in the GLSAU #204 core.

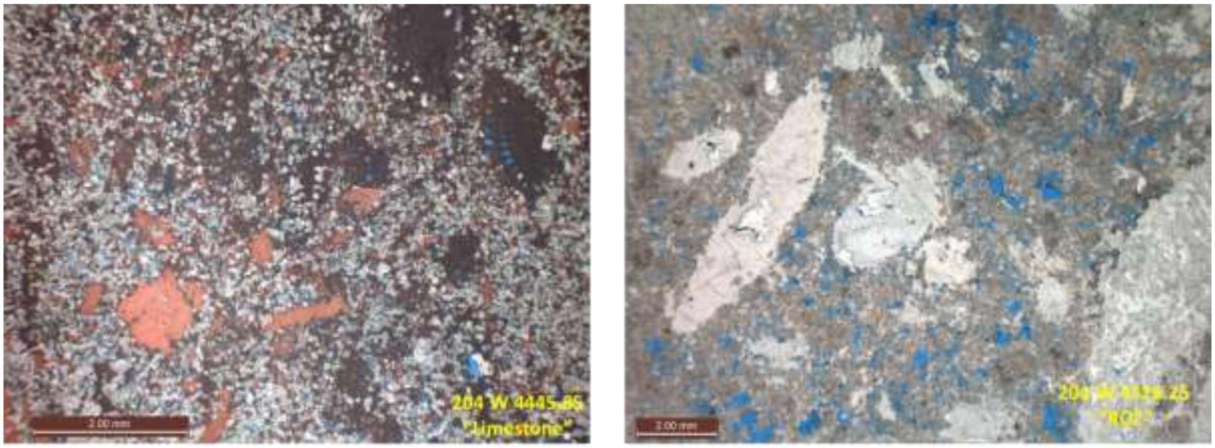


Figure 2.20. Comparison of (A) Limestone below ROZ with small euhedral dolomite crystals (white crystals) and fusulinids with preserved internal structure, #204 W GLSAU, depth 4445.85, with (B) subhedral to anhedral dolomite with fusulinids replaced with anhydrite from ROZ, depth 4326.25.

Near the top of the cored interval in the GLSAU #204 core, fusulinids decrease significantly and grains appear to be mostly peloids and ooids. Grains are both leached and preserved as ghosts. Intercrystalline and moldic pores average 5-10%. Note that the core appears less "oil stained" because the interval is situated in the gas cap for the field.

The first evidence of stromatolitic algal laminated tidal flat deposits occurs at the top of the GLSAU #204 core. Porosity is significantly reduced (1-3%). Cycle tops are picked relatively easily in intervals that display tidal flat deposits.

Both the GLSAU #190 and the GLSAU #204 cores contain San Andres lithologies that are skeletal (fusulinid/crinoid/brachiopod) wackestones to grain dominated packstones. The basal 30 feet of the # 190 core also contains rugose corals and bryozoa, indicating that the most open marine deposits occur at the bottom of the core. The top 10-20 feet of the #204 core is composed of peloidal (oolitic?) grain-dominated packstones and also displays the first stromatolitic algal laminated deposits. Porosity is slightly higher below the ROZ, but all intervals have porosities in the 6-12 % range except the stromatolitic algal laminated lithologies.**2.2**

2.2 SUMMARY OF CORED WELLS IN 12-COUNTY STUDY AREA

2.2.1 Examples of both Greenfield and Brownfield ROZ's

Within the 12-county study area there are a number of examples of both Greenfield and Brownfield ROZ's. Cores from three wells: the Byrd #1 Pharr, in Yoakum County, Anschutz #1 Keating in Gaines County, and the Legado #203 RW GLSAU in Ector County, Figure 2.21, provide an opportunity to review the spectrum of ROZ related reservoir properties, facies, and diagenetic overprints.

Figure 2.21. Location of Byrd #1 Pharr, Anschutz #1 Keating, and Legado #203 RW GLSAU wells.

2.2.1.1 "Attic Oil" - A Minor Main Pay atop an ROZ, Byrd #1 Pharr, Yoakum County, TX.

The Byrd #1 Pharr is located in north-central Yoakum. It is located on the western edge of a low relief structure in the Henard Field, Figure 2.21. The well was drilled into the top of the "San Andres" pay and 60' of core was recovered. Of that 60', the lower 40' exhibit porosity and oil stain. This well represents the regressive shallow subtidal to intertidal to supratidal portion of the lower San Andres interval, Figure 2.22, that produces over much of the Yoakum County portion of the Northwest Shelf and in the Slaughter Levelland trend to the north in Hockley, Cochran, northern Lea, southern Roosevelt, and eastern Chaves Counties. The producing interval is equivalent to the Chambliss Zone in the Manzano and Walsh San Andres horizontal play to the southwest. The cored interval in this well represents the uneconomic transition from the porous and permeable open marine environment deeper in the section to the sabkhas rich upper portion of the G 4 sequence of the "lower San Andres", Figure 2.23. The well IP'd for 10 BO from 5210-5235'. No water or gas were reported. The well has produced 3,842 BO in the first year of production. Compare that with the Walsh #1H Winbert, in an example of a horizontal

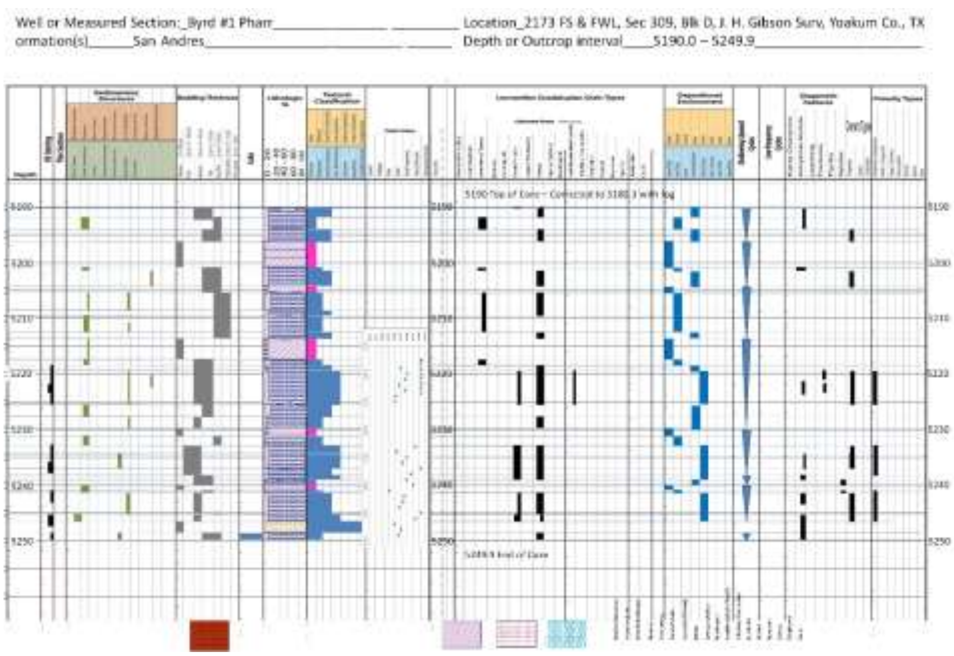


Figure 2.22. Core description of Byrd #1 Pharr, pink bars in lithology textural classification represent anhydritic sabkha cycle tops. Oil stain noted in column on far left. Only the 3 lower cycles contain enough porous shallow marine grain-rich packstones be oil stained reservoir.

	Guad Mts.	Downdip Northwest Shelf	Updip Northwest Shelf NM	Updip Northwest Shelf TX	Delaware Basin	Central Basin Platform	Eastern Shelf, NE Midland Basin
	Guad. 10	Grayburg 1 Premier Sand	Evaporites		U. Cherry Cnyn	L. Grayburg	L. Grayburg
Upper San Andres Composite Seq. CS10	Guad. 9	Upper S A Lovington Sand	Evaporites		L. Cherry Cnyn	U. San Andres Lovington Sand	
	Guad. 8	Upper S A	P1-3	Slaughter 1-3		U. San Andres	U. San Andres Cedar Lake, Welch
	Guad. 7				Brushy Canyon		
	Guad. 6						
	Guad. 5						
Lower San Andres Composite Seq. CS9	Guad. 4	Upper S A2	P4	Slaughter 4	U. Bone Spring or Cut Off	San Andres	San Andres
	Guad. 3	Upper S A 1	P5	Slaughter 5		San Andres	
	Guad. 2	Middle S A2	P6			McKnight Shale	
	Guad. 1	Middle S A 1	P7				
	Leonardian 8	Lower S A 2	P8		Pipeline Sh	Holt	Lower San Andres Howard Glasscock, Iatan, Ddiamond M
	Leonardian 7	Lower S A 1	P8				
	Leonardian 6	Glorieta	Glorieta		Bone Spring	Glorieta	San Angelo

Figure 2.23. Stratigraphic Terminology, Kerans, 2006, Modified after Kerans, 2000, Trentham and Smith, 2002. Red outline is Pharr interval of interest.

well which fraced the open marine and subtidal to intertidal seen in the #1 Pharr Main Pay, and included the upper part of the ROZ. The #1H Winbert produced 60,870 BO over the same time frame as the #1 Pharr produced 3,842 BO from a vertical well in the subtidal to intertidal interval only.

The production in the #1 Pharr is typical of San Andres wells that are strato-structural traps, but do not have significant closure (usually associated with deep structures). The “oil column” is proposed to have been left un-swept when the regional “Mother Nature’s Waterflood” flushed the deeper open marine portion of the section. This unswept interval is a result of there being thin cycles composed of shallow subtidal, intertidal, and sabkha facies, with poor lateral permeability, Figure 2.22. Regionally, this facies association is representative of an overall falling sea level which culminates in sabkha rich interval beneath the exposure at the top of G 4 and the overlying Pi Marker.

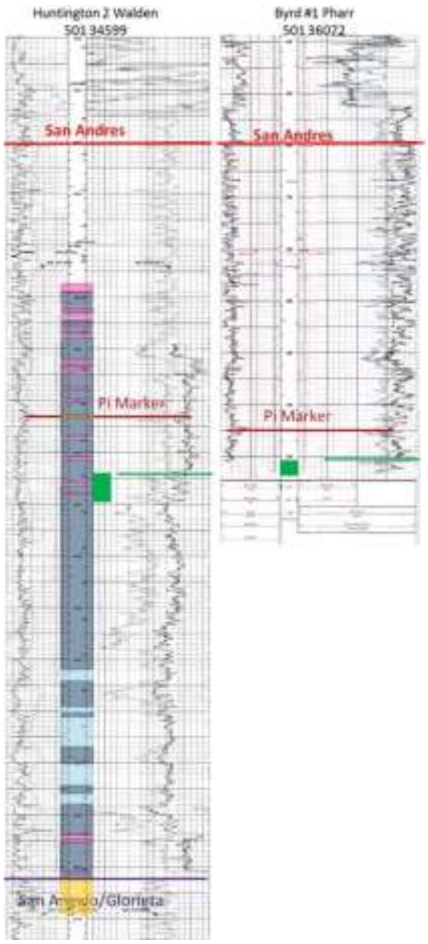


Figure 2.24. The Byrd #1 Pharr and Huntington #1 Walden, producing interval in area in green.

The thick porous interval seen in the Huntington #2 Walden beneath the shallow subtidal to Sabkha cycles (see in green on the logs in Figure 2.24) represents a deeper water, shoal capped and open marine sequence that is typically, at least in part, the ROZ. For a more complete review of the regional stratigraphy, see the Regional Geology section.

As seen in the core description, Figure 2.22, there are 6 cycles. Each one shallows up to a sabkhas/anhydrite cap. Only the lower 3 have subtidal bases with porosity and oil stain. This interval represents the regressive portion of the lower San Andres sequence. Deeper in the section, there are thicker sequences of open marine and shoal capped cycles. This dolomitized section is >250' thick and in large portions of Yoakum County, where it is not productive (Wasson Field), it is the ROZ.

2.2.1.2 The Anschutz #1 Keating, Gaines County, TX: A True ROZ

The #1 Keating was drilled on a Clearfork seismic anomaly in 1990, and TD'd in the lower Clearfork. Whole core was recovered from 2 intervals in the San Andres after mud log shows were encountered. The upper interval, 5464-5503', Figure 2.25, had oil saturations ranging from a trace to 37%. The well was then drilled for 47'. But as they continued to see 40-60% Bright Yellow Fluorescence, good dry and wet cut, and some gas, the interval 5550 – 5601 was also cored. Additional side wall cores were recovered to evaluate the section with oil shows on mudlogs (5512 – 5550', 5616 -5625', 5719-5724', 5550 – 5603'). Oil saturations of 8.5 – 34.5 were seen in the sidewall cores.

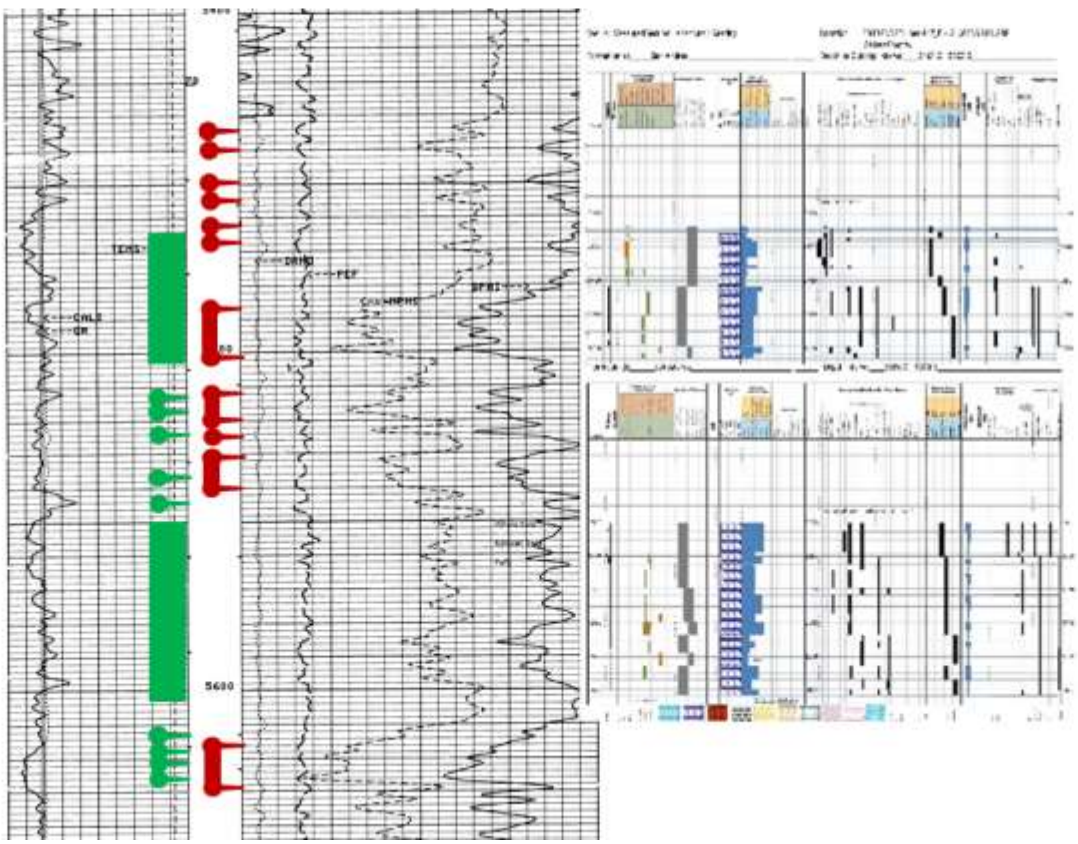


Figure 2.25. Well log and core description for the Anschutz #1 Keating, Gaines County, TX. The two cored intervals and the drilled interval between them are in the Greenfield ROZ. The GREEN intervals are recovered core, both whole core (solid bar) and sidewall (spikes), and the perfed intervals are shown in RED. The perfs above the cored ROZ intervals tested the shallow subtidal to intertidal "cap" on the open marine ROZ. The well produced 8 BO and 3701 BW before being plugged.

The lower cored interval in the Keating is composed primarily of fusulinid rich wackestone to packstone open shelf carbonates (5885'–5601', EOC). The interval from 5458'–

5584’ is composed of open marine to shoal-capped marine grain rich packstone to grainstone facies. The upper portion of the cored interval is composed of restricted marine to tidal flat facies with reduced permeability and porosity.

The results of the core and log analysis convinced Anschutz to complete the well. They perfed 5434’-5540’, acidize with 500 gal 15% mud acid, and swabbed 656 BW with a Trace of oil over 2 weeks. Additional perfs, 5616’–5628’, were added, acidized with 500 gal 15% acid and an additional 135 BW were swabbed with a Trace of oil.

The well was shut in and further analysis of the core and logs resulted in Anschutz putting the well on pump. The well recovered a total of 1195 BW before recovering any oil. Over the next 45 days, the well recovered 2606 BW and 8 BO before Anschutz gave up and plugged the well.

This is a “Classic” ROZ response to an attempted primary completion.

The #1 Keating is located on the northern edge of the Central Basin Platform, facing the George Allen Field across the San Simon Channel on the southern margin of the Northwest Shelf. Trinity, operator of the George Allen Field, has initiated a peripheral Greenfield ROZ flood initially recovering large volumes of water before recovering oil.

2.2.1.3 Kinder-Morgan’s Tall Cotton Project, a True Greenfield ROZ

Kinder Morgan’s Tall Cotton Project, Gaines County, TX: The first true Greenfield project without an associated Main Payzone is offset one mile to the southeast to the #1 Keating and within the same section as the #1-427 Charlene, the only well in the Bittner Field, which made 138 BO from a 47’ thick SADR Zone. The review of these wells provided the information necessary to establish the presence of a significant Greenfield ROZ in the area. Presently there are 9 - 5 spot patterns in the Tall Cotton project (see Chapter 7 Section 7.3.3. This project is injecting CO_2 into, and producing from, the same interval as the attempted completion in the #1 Keating. It is assumed that because of the proximity of the Tall Cotton project to the #1 Keating, and the lack of structural complexity in the area, that the facies in the tall Cotton project will be the same as the distribution of facies in the Anschutz #1 Keating core.

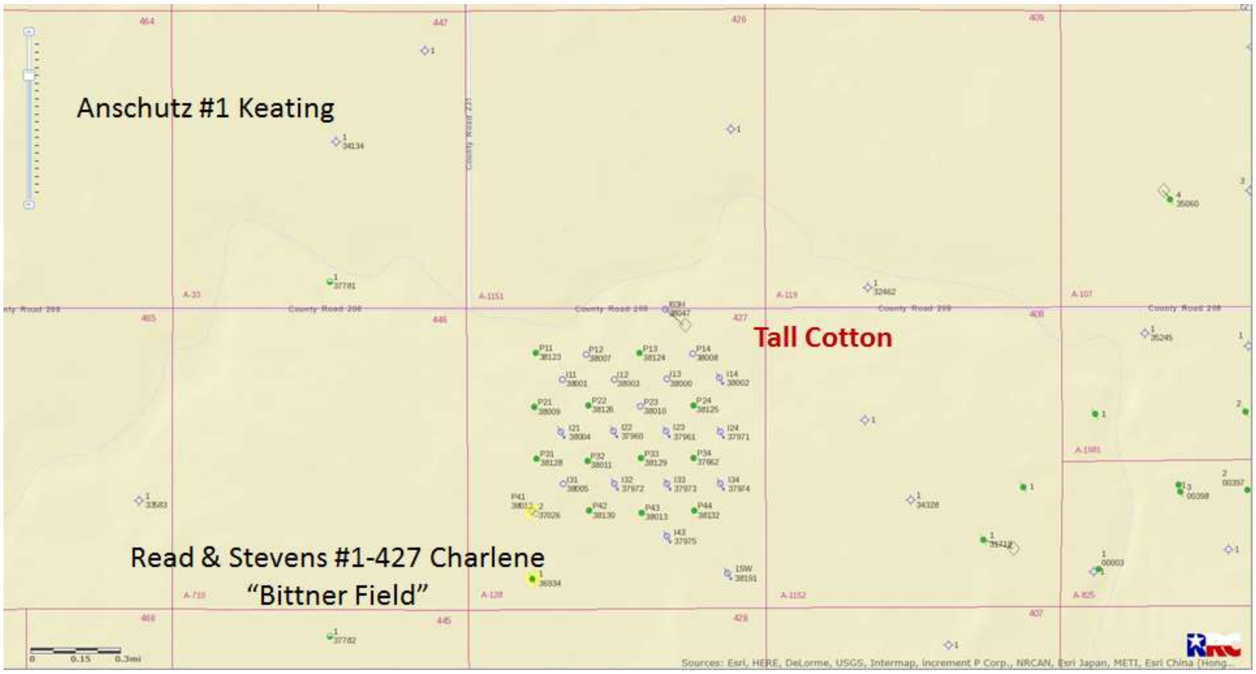


Figure 2.26. Location of Anschutz #1 Keating, Read and Stevens #1-427 Charlene (Bittner Field) and the Tall Cotton Greenfield ROZ project, Gaines County.

2.2.1.4 Goldsmith Landreth San Andres Unit (GLSAU) #203RW (Injector Offset Well Core), Ector County, TX: Proof of Mobilized Oil from the Residual Oil Zone

As part of the commingled Goldsmith Landreth Main Pay (MP) and Residual Oil Zone (ROZ) CO_2 flood in the Goldsmith (San Andres) Field, a core was taken in both the MP and ROZ with a partial objective to demonstrate the sweep efficiency of the MP and ROZ flood. The well, #203 RW GLSAU, was a replacement for one of the original injectors in the initial producer-centered five-spot pilot. Oil response was excellent and very rapid in the pilot and, early in the injection history, it was determined that for conformance reasons, it was necessary to plug back from the fast processing lower unit of the ROZ (LROZ), and concentrate the injection in the upper member of the ROZ (UROZ). The operator's most desirable solution was to replace the original well (#203W) and drill and core a replacement well (#203 RW). The new well was drilled ~135' from the original well, just outside the original pattern. Both the MP and ROZ was cored and it became apparent that there were elevated oil saturations (So) in the LROZ when compared to other cores taken before the inception of the CO_2 flood. These elevated So values just outside the pilot pattern serves as proof of oil 'bank' development in LROZ that had provided the fast response inside the pattern and was caught in the act just outside the pilot pattern. As CO_2 had been injected in the lower ROZ for a brief period, the flood front had advanced to the center producer but not moved far beyond the location of the replacement well (#203 RW) outside the injector.

The reservoir portion of the ROZ is composed of 2 parasequence sets of fusulinid rich outer shelf mud rich to mud poor packstones (in both the UROZ & LROZ). An interval of deeper water fusulinid dominant wackestone to mudstone separates the two ROZ CO_2 targets. The base of the ROZ is coincident across most of the field with the transition from predominantly limestone below to dolomite above. This transition is often seen to be associated with the base of the ROZ, as is the presence of native sulfur. The faster processing LROZ represents a heavily dolomitized and leached sequence just atop the limey base of the ROZ. The MP is composed of an overall shallowing upward sequence, from open marine to tidal flats, where there are a series of individual shallowing upward individual cycles, many of which have Solid Hydrocarbon Residue (SHR) at the base of the cycle suggesting each cycle acts as a separate flow unit.

2.2.1.5 Trinity's George Allen Field, Gaines County, TX: A "Peripheral Greenfield" CO_2 Flood.

Most San Andres field have "Brownfield ROZ's" beneath them. Once you have delineated the field with wells drilled beyond the field boundaries, you're historically in 'dry hole' country, encountering only "Greenfield ROZ's".

The George Allen Field has a thin main pay of less than 100' which has been delineated and waterflooded for >30 years, Figure 2.27. Injection of CO_2 into the new "Greenfield" Patterns is just over a year old, Figure 2.28. As of May 2015, the 3 easternmost **ROZ only** producing wells have produced as much as 200 BOPD, more than the rest of the field combined.

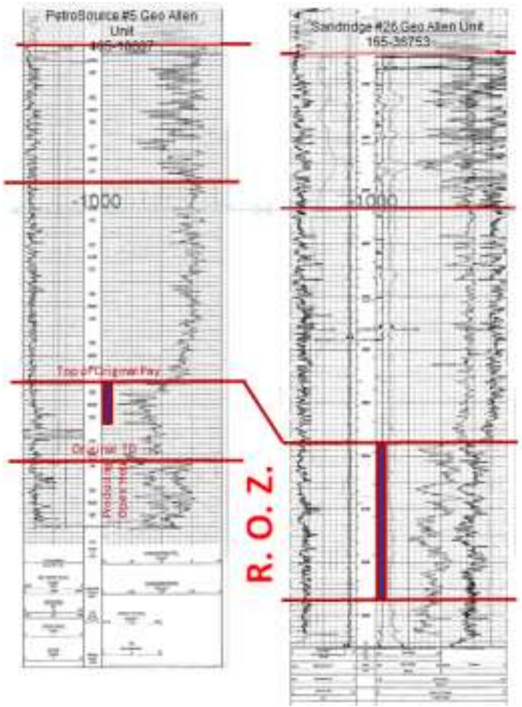
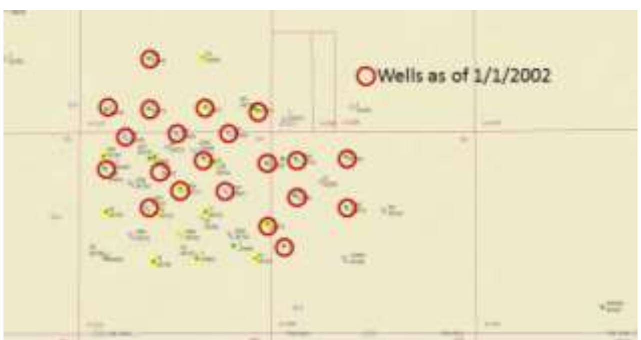


Figure 2.27. George Allen Field, Main pay in log on left, Peripheral ROZ in log to right.



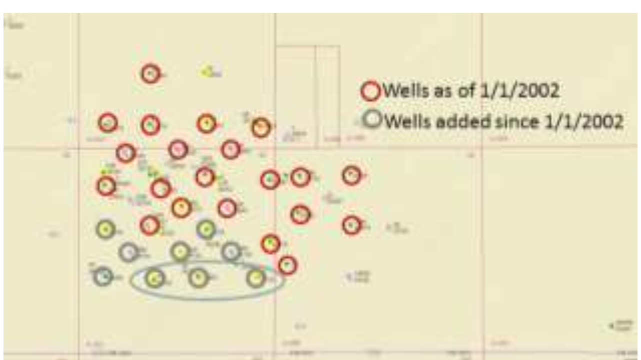


Figure 2.28. George Allen Field wells as before Peripheral CO2 flood (above) and after CO_2 flood initiation (below).

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Chapter 3 - MAPPING OF ROZ FAIRWAYS IN THE SAN ANDRES FORMATION

Author: L.S. Melzer

3.1 BACKGROUND

During the course of the time between the first DOE ROZ report (Ref 3.1 {2006}) and the first RPSEA project work (Ref 3.2) leading up to the proposal for this study (RPSEA II), some preliminary efforts were undertaken to develop first drafts of the fairways of sweep. The first work was plainly simple in concept but turned out to be quite representative as the later stage data was acquired. The western region of the Permian Basin was selected as the area of investigation for the RPSEA I study for the hydrodynamic modeling work since it had sufficient well data available but was isolated from ROZ related commercial activity.

One of the key alterations of the ancestral Permian Basin was a western uplift, outcropping of the San Andres in central New Mexico, and development of meteorically derived waters that swept very slowly downdip in the San Andres formation. The waters worked through what were to become the producing areas of the Permian Basin and out the eastern side of the Basin to the lower elevation ground surface there. The areas of lateral sweep were dubbed fairways where the reservoir was of sufficient porosity and permeability to have allowed oil entrapment during the Mesozoic era and sufficiently interconnected to allow water movement from to the westward uplifts in Laramide and the early Tertiary era.

This relatively simple version of the geologic history of the Permian Basin would help explain the presence of a paleo entrapment of oil prior to the uplift that was very widespread through the Permian age carbonate shelf areas of the Permian Basin. And, because of the paleo trap and widespread (but volumetrically inefficient) sweep of portions of it, the rocks had retained some of the oil saturation, manifested as immobile, i.e., residual oil. When these rocks were drilled, their cuttings carried to the surface possessed shows of oil very much like the zones that still contained mobile oil in the pore spaces.

This ROZ model would also explain the numerous San Andres oil fields (main payzones) as structural 'bumps' of reservoir quality rock atop the laterally swept fairways and isolated from the deeper hydrodynamic sweep. It seemed entirely logical then to outline those producing oilfields within the areal limits of the ROZ fairways. Therefore, the first iteration of the fairway mapping was to 1) map the San Andres formation producing fields, 2) check for alignment in areal trends, 3) verify that the trends were consistent with the understanding of reservoir porosity within the San Andres formation, 4) map those trends, and 5) review samples of deep wells beneath those fields to be sure the ROZs existed below them. Figure 3.1 is the very first map created in an attempt to outline the extent of the ROZ fairways. This map formed the basis for the ROZ Symposium that was organized as a part of RPSEA I wherein many of the oilfield professionals were invited to exchange their experiences of witnessing great oil shows but establishing no primary oil production. It also provided the impetus to name the fairway trends and begin the process of understanding the ages of each, how they might converge or diverge geographically.

From the first fairway map and later updated versions, the Permian Basin San Andres fairways were prioritized by county. Four initial counties, Yoakum, Gaines, Terry and Dawson were chosen as representing the largest potential for vast ROZ oil resources. The RPSEA II team (authors of this report) chose those counties to begin the characterization work and to develop the methodology for the ROZ resource assessment. It was determined that eight additional counties could be completed and those were chosen to be Andrews, Martin, Winkler, Ector, Midland, Ward, Crane and Upton.

Figure 3.2 is the latest and final version of the San Andres fairway map. The twelve counties are identified on the map as well. Note that many of the major San Andres oilfields are labelled along with SACROC, Salt Creek and Katz which are key older (Pennsylvanian) carbonate fields under CO_2 flood. Also shown is the first pure greenfield CO_2 flood called Tall Cotton in Gaines County (see Chapter 7, Section 7.3.3).

The results of the fairway assessment of the San Andres greenfield ROZ resource are reported in Chapter 7.

Figure 3.1 – Original San Andres Fairway Mapping (2009)

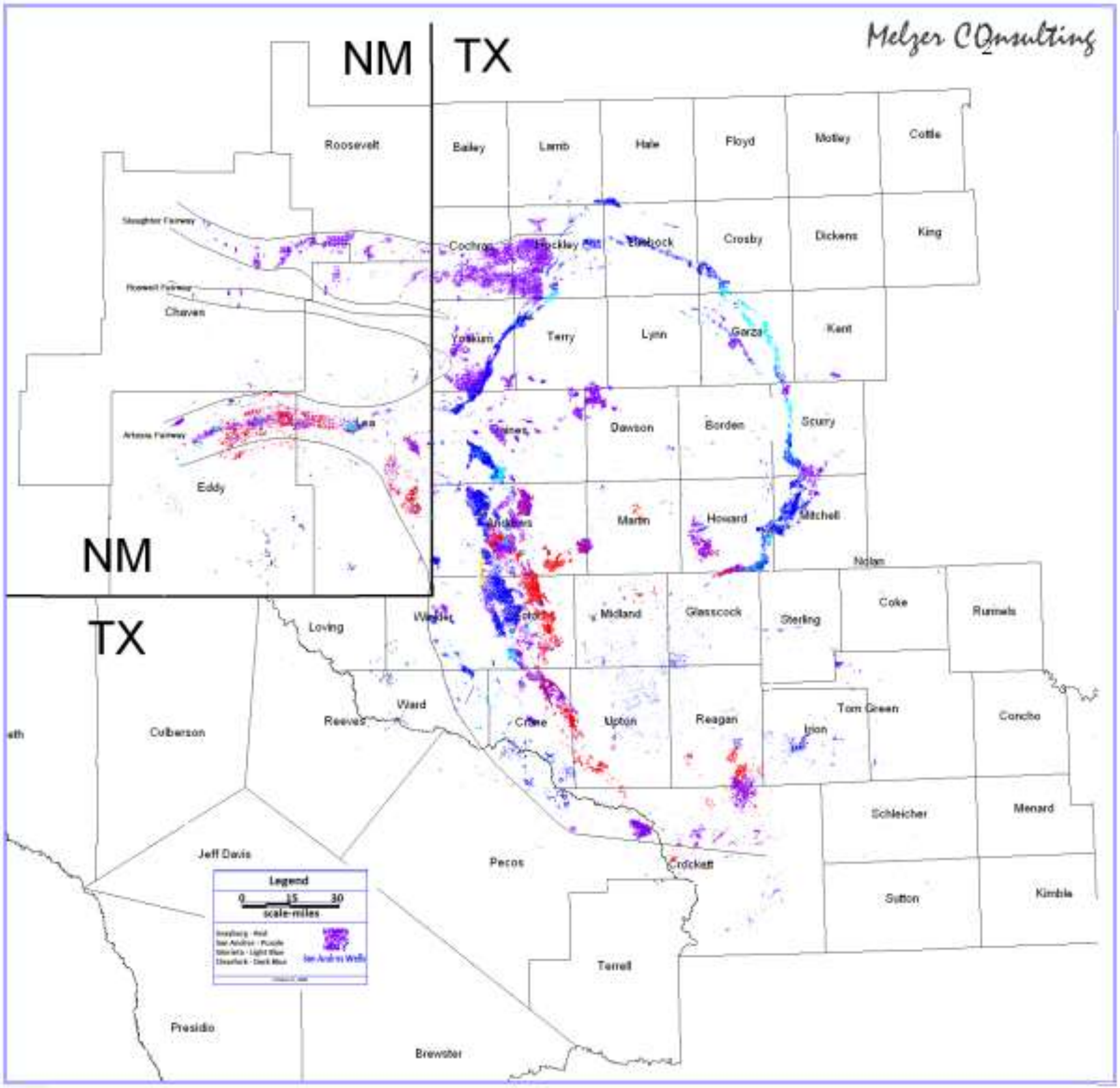
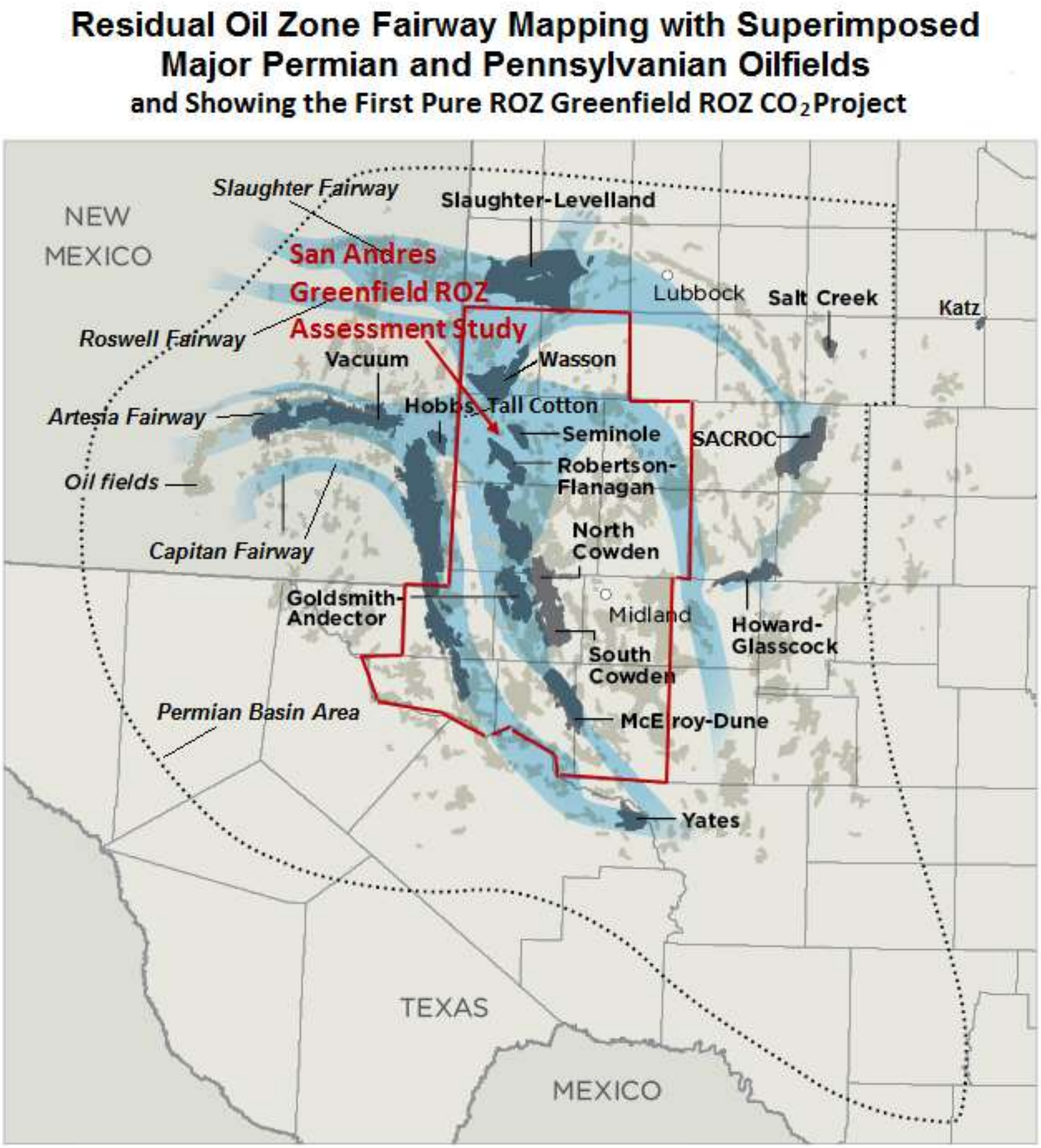


Figure 3.2



Residual Oil Zone Fairway Mapping with Superimposed Major Permian and Pennsylvanian Oilfields
and Showing the First Pure ROZ Greenfield ROZ CO_2 Project
Slaughter Fairway
Slaughter-Levelland
NEW MEXICO
San Andres Greenfield ROZ Assessment Study
Lubbock
Salt Creek
Katz
Roswell Fairway
Vacuum
Wasson
Artesia Fairway
Hobbs
Tall Cotton
Seminole
SACROC
Oil fields
Robertson-Flanagan
North Cowden
Capitan Fairway
Goldsmith-Andector
Midland
Howard-Glasscock
South Cowden
Permian Basin Area
McElroy-Dune
Yates
TEXAS
MEXICO

3.2 REFERENCES

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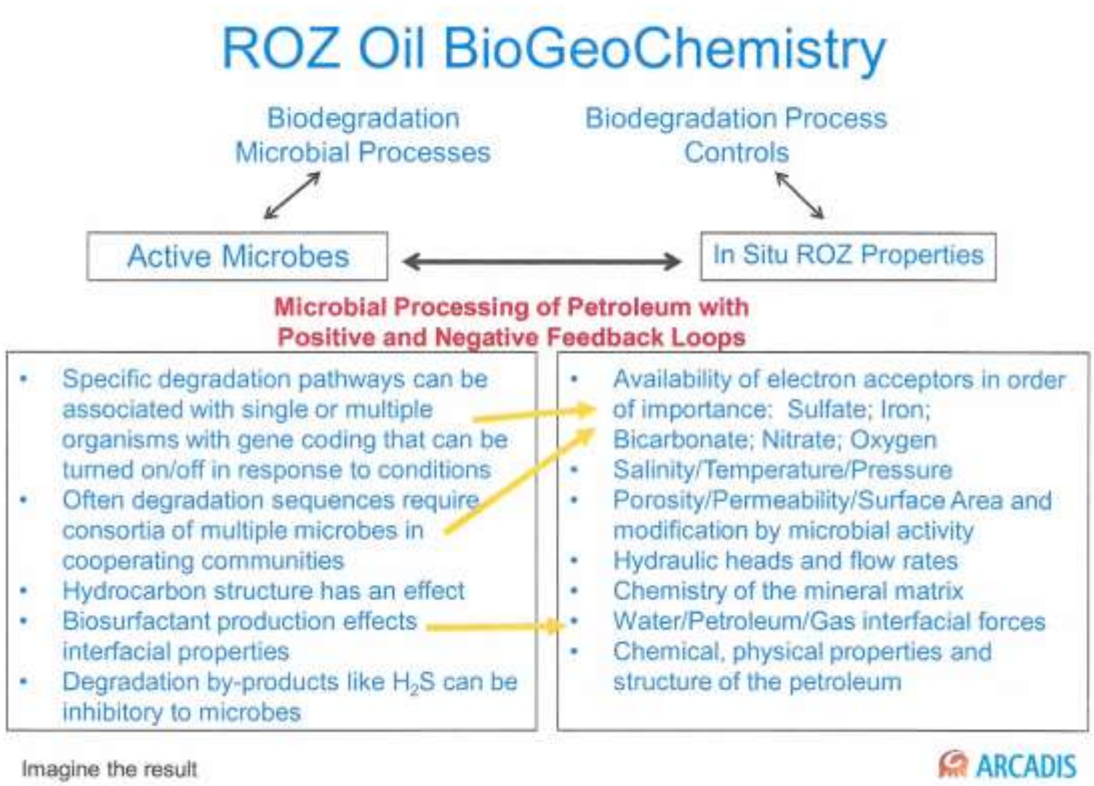
CHAPTER 4 – ROZ OIL BIOGEOCHEMISTRY

Author: David Vance

4.1 INTRODUCTION

The major and trace chemistry in all phases within San Andres ROZs that include water, oil, gas, and minerals are controlled by two dominant processes. One is biogeochemical processing by indigenous microbial organisms, and the second are the physical effects of water sweeping through the ROZ over geologic time frames. The following discussion will be focused largely on the biogeochemical controls and processes that effect all phases in an ROZ. These biogeochemical reactions are interrelated, Figure 4.1 outlines key processes and controls.

Figure 4.1



The San Andres in the 12-county study area does contain sulfate, both in the mineral matrix most often as anhydrite and in formation water. Table 4.1 provides a summary of geochemical data from 295 produced waters from the San Andres in the 12 county area. Exhibit 4.1 shows the relationship between TDS and sulfate, the water has abundant sulfate with a trend for sulfate to increase with TDS that is associated with increased solubility of calcium sulfate minerals with increased solution TDS. Exhibit 4.2 illustrates the relationship of calcium and sulfate, with dissolved calcium declining with sulfate concentrations, driven by chemical equilibrium between the two dissolved species and mineral calcium sulfate. Lastly, Exhibit 4.3 shows the relationship between bicarbonate and sulfate. With bicarbonate first increasing with sulfate concentration then declining. This is likely reflective of relationships between the dissolved carbonate and carbonate mineral phases in addition to some potential microbial inhibition processes that could cause a decline in the production of carbon dioxide from petroleum biodegradation. Irrespective it is clear that sulfate is a readily available biologically reactive component in the San Andres.

Exhibit 4.1

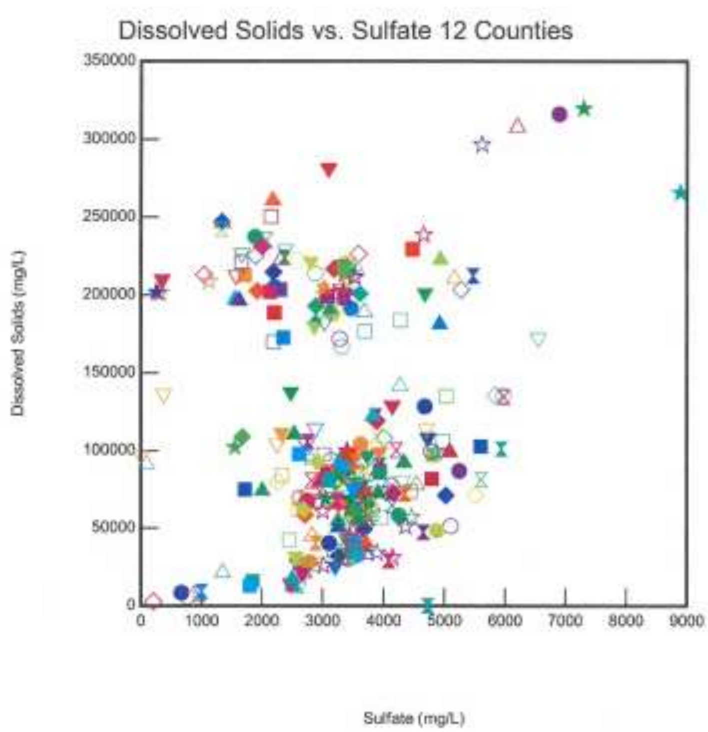
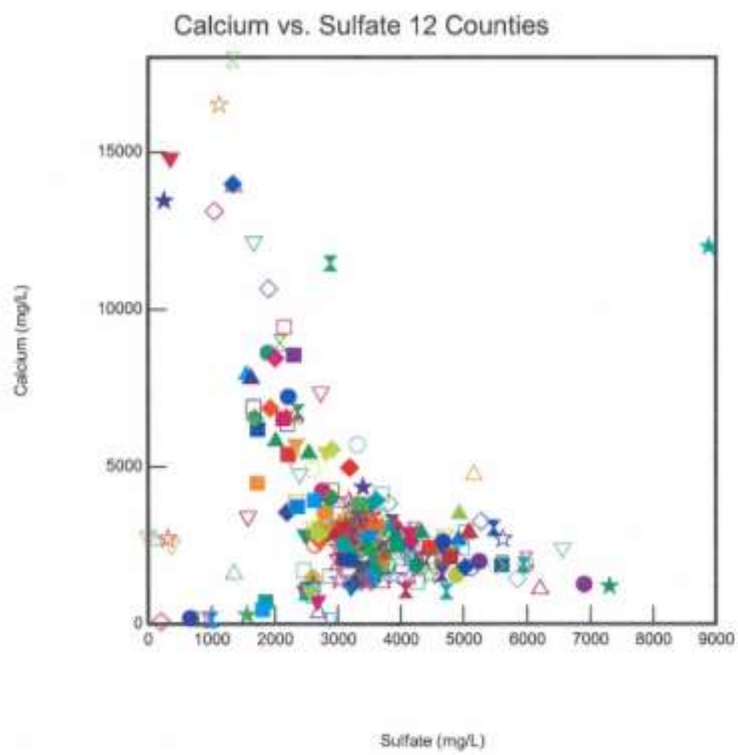
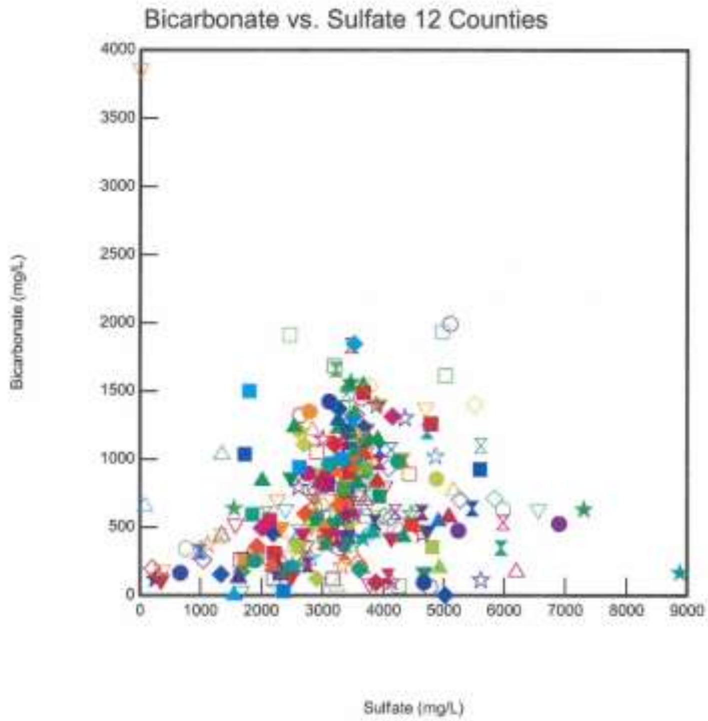


Exhibit 4.2



Calcium vs. Sulfate 12 Counties
Calcium (mg/L)
15000
10000
5000
0
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Sulfate (mg/L)

Exhibit 4.3



Most abiotic geochemical reactions are driven by the transfer of protons without electrons, which is in essence acid/base chemistry. In contrast the chemistry of life is based on oxidation/reduction reactions that entail the transfer of protons and electrons. Almost all microbial processes exploit chemical reactions that thermodynamically yield energy that in many cases, under abiotic conditions, may have poor reaction kinetics. Microbial utilization accelerates kinetics and the microbes derive energy by essentially acting as electron transfer agents in the process. Microbial driven biogeochemistry significantly contributes to the physical dynamics and residual oil concentrations in Residual Oil Zones (ROZs).

Two of the three primary kingdoms of life are active in ROZs:

- Bacteria
- Archaea

In this discussion the term microbe (or its derivatives) will be used for both. The reason is that in size and shape bacteria and Archaea appear to be similar and until relatively recently both considered to be simply prokaryotes (or bacteria) by the scientific community, but with the availability of DNA analysis it was discovered that the two have a distinctly different evolutionary history and different internal biochemistry that is sufficient enough to justify the creation of an entirely new kingdom of life to place Archaea in. In addition, the difference are important because in general Archaea are viable over a broader range of environmental conditions.

Microbial life has been found to be extremely robust and capable of surviving in a wide range of environmental conditions. Aside from the chemical environment, which is a thread throughout this discussion, the physical environment can vary with regards to pressure and temperature. Temperature has by far the greatest effect on the bulk biochemistry of a microbe and provides the most evident limits to a viable environmental envelope. Microbial life can be divided into four temperature ranges:

- Hyperthermophiles with a temperature optimum greater than 80^{o}C
- Thermophiles between 45^{o}C to 80^{o}C
- Mesophiles between 15^{o}C and 45^{o}C
- Psychrophiles less than 15^{o}C

Microbial activity in ROZs is dominated by Mesophiles and Thermophiles.

Pressure is manifest at the high end by hydrostatic conditions in the deep ocean or crust and the low by conditions in the upper atmosphere. Microbes occupy the deepest depths of the ocean, in addition they have been found in deep terrestrial subsurface environments and as high as 77 km in the atmosphere (Whitman, 2009).

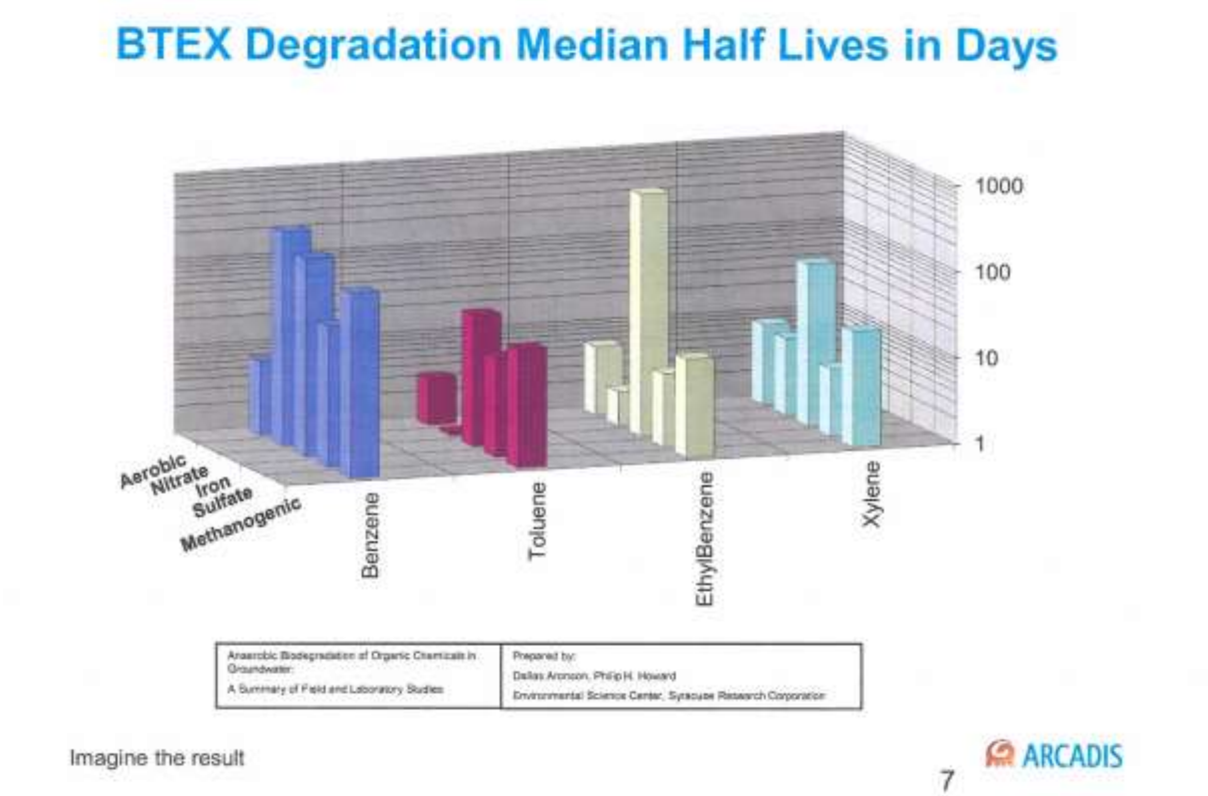
Major biogeochemical oxidation/reduction pathways for microbes include utilization of:

- Oxygen
- Nitrogen
- Iron
- Sulfur

- Hydrogen
- Methanogenesis

Overall these degradation pathways represent a fairly complex system. Figure 4.2 provides a ready summary of it. In that figure the degradation kinetics of several hydrocarbons (BTEX and naphthalene) are illustrated for various electron acceptor systems. The half life is simply the time it takes for a half of the hydrocarbon mass to degrade (assuming 1st order or typically pseudo first order reactions).

Figure 4.2



There are other pathways that involve other potentially labile transition metals or metalloids and there are many subsets of oxidizing and reducing reactions involving nitrogen, iron and sulfur chemistry. The process responsible for the production of sulfate, hydrogen sulfide and sulfide oxidation producing elemental sulfur are dominant redox pathways observed in San Andres ROZs of the Permian Basin.

Sulfur is an extremely important inorganic energy source for microorganisms, it can yield up to 8 electrons in a step wise fashion from sulfide (-2) to sulfate (+6).

$$CaSO_4 + CH_4 \rightarrow CaCO_3 + H_2O + H_2S$$
$$\mathbf{S^{6+} + C^{4-} \rightarrow C^{4+} + S^{2-}}$$

Additional abiotic or biological processing can yield a wide variety of sulfur based reaction products, which can in turn participate in additional processes (Douglas, 2005).

In contrast iron is also extremely bioreactive, but iron redox reactions involve only one electron, whether ferric iron acting as an electron acceptor and reducing to ferrous iron, or ferrous iron acting as an electron donor and oxidizing to ferric iron. Although a minor source of microbial energy (on a molar basis), iron biogeochemical processing significantly serves to provide ready phase changes from solid phase iron oxides to soluble ferrous iron or reverse reactions that can also include iron sulfides. Those process can impact the physical character of the flow system.

It has long been recognized that petroleum hydrocarbons are biodegraded by indigenous microbial populations. In a historical review published by Zobell in 1943 there is a discussion that includes the identification of petroleum degradation by sulfate reducers in 1886 and by aerobic bacteria in 1913. The essence of hydrocarbon biodegradation is oxidation. In a manner similar to combustion, indigenous microbial populations have the ability to oxidize petroleum hydrocarbons for energy, and also growth using multiple pathways. Given the discussion above this process appears to be robust and universally available.

Oxidation is the dominant intrinsic degradation process for petroleum hydrocarbons, whether under aerobic or anaerobic conditions (Aronson and Howard, 1997; Wiedemeier et al, 1998; Saleem, 1999; and Azadpour-Keeley, 1999). Oxidation and reduction reactions fundamentally involve the transfer of electrons. A substance that is oxidized loses electrons, and one that is reduced gains electrons. An oxidizing agent is a substance that readily accepts electrons causing oxidation of the substance that loses the electrons (electron donor) and is oxidized. The most familiar oxidizing agent (electron acceptor) harnessed by microorganisms is oxygen; however, any process (biologically or chemically mediated) that removes electrons from other substances is causing oxidation.

In San Andres ROZs the dominant biogeochemical process is the anaerobic oxidation of petroleum constituents via sulfate reduction. That metabolic pathway is such that the reduction process always goes completely to hydrogen sulfide, not intermediate oxidation states such as elemental sulfur. In system in which sulfate reduction is taking place the formation of species with a charge greater than that of sulfide (-2) had to have taken place via some additional available oxidation process.

In the case of sulfate reduction it is possible for thermogenic sulfate reduction to reduce sulfate while oxidizing hydrocarbons by an abiotic reaction (Yue et al, 2006). However, it is a process that takes place at elevated temperatures, around 140º C (Worden et al, 1995), these temperatures are representative of the deep Permian Basin, not of the San Andres Formation.

Aerobic respiration does not take place in Permian Basin ROZs because oxygen is not readily available, nor is nitrate.

Iron is almost ubiquitous in the subsurface. In some cases iron oxides may make up low percent concentrations of the mineral matrix. The processes driven by iron reducing microbes that degrade petroleum hydrocarbons are extremely common. There are two limitations with regards to effectiveness. One is the poor stoichiometry; ferric iron only accepts one electron during the conversion to ferrous iron. This results in the iron to carbon stoichiometric mass ratio of 21 to 1. Second, iron is present as iron oxide minerals. The biologically available iron is limited to the surface of those minerals which may limit the rates of the iron based biodegradation process as well. If there is ferrous iron produced it will react with hydrogen sulfide generated by sulfate reduction to provide near complete control of the hydrogen sulfide. However, iron is scarce in Permian Basin Carbonate ROZs.

4.2 SULFATE REDUCTION

Sulfate reduction is proving to be a dominant degradation pathway for petroleum hydrocarbons in Carbonates of the Permian Basin. It also plays a critical role in the creation of and establishing the physical setting and character of ROZs.

There are a couple of factors that can impact the biodegradation of hydrocarbons by sulfate reduction. One is the accumulation of hydrogen sulfide. Hydrogen sulfide is the daughter product of sulfate reduction and it is well recognized that elevated concentrations of hydrogen sulfide are inhibitory to sulfate reduction.

Another distinctive characteristic of the dynamics of sulfate reduction are the changes that take place in the specific biogeochemical processes as the available sulfate concentration declines. This process can be summarized as follows:

- As the sulfate concentration drops below 100 mg/L the sulfate reducing microbes begin to engage in intercellular storage of sulfate.
- Another transition begins in the range of 30 to 60 mg/L sulfate, cell growth stops, and
  - Sulfate is used for energy only, and
  - Metabolic pathways change to increase the specific sulfate reduction rate making more efficient use of the available sulfate
- In the range of 20 to 5 mg/L isotopic studies show that sulfate reduction stops completely and methanogenesis takes over. This generally takes place as the ORP conditions drop below – 100 mV.

4.2.1 Additional Sulfur Chemistry in San Andres ROZs

During the exploration, development and production of petroleum from the San Andres in the Permian Basin a phenomena termed "black sulfur water" has frequently been observed. One characteristic of that type of water is that over time the black suspended material disappears. It is likely that the dominant constituent in black sulfur water is polysulfide. Polysulfides involve sulfur in the form of elemental sulfur.

Another common observation in core within productive zones of the San Andres (and San Andres ROZs) is the presence of elemental sulfur in the mineral matrix of the core. The most common surficial means for the production of elemental sulfur from hydrogen sulfide is oxidation by oxygen. However, the San Andres is at a sufficient depth that it is isolated from atmospheric sources of oxygen. There are other reaction process that can produce element sulfur from hydrogen sulfide in situ within the San Andres. They include:

SO_4^{2-} + $\mathbf{3H_2S}$ $\rightarrow$ $\mathbf{4S^0}$ + $2OH^-$ + $2H_2O$ (Feely and Kulp, 1957)

$CaSO_4$ + $\mathbf{3H_2S}$ + CO_2 $\leftrightarrow$ $\mathbf{2S_{2(s)}}$ + $CaCO_3$ + $3H_2O$ (Hutcheon et al, 1995)

SO_4^{2-} + $\mathbf{3H_2S}$ + $2H^+$ $\rightarrow$ $\mathbf{4S^0}$ + $4H_2O$ (Alonso-Azcarate et al, 2001)

$CaSO_4$ +$4CO_{2(g)}$ + $3Ca^{2+}$ + $4H_2O$ $\rightarrow$ $4CaCO_3$ + $\mathbf{H_2S_{(aq)}}$ + $6H^+$ + $\mathbf{2O_{2(g)}}$ (Richard et al, 2005)

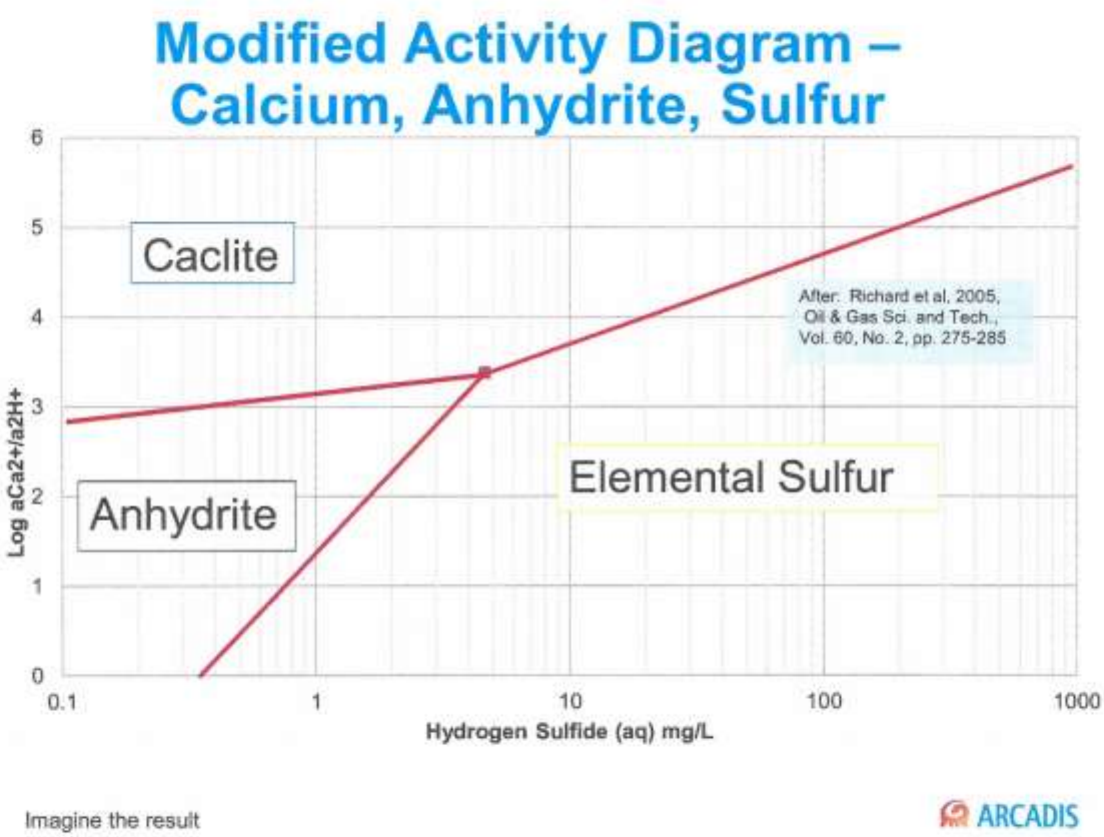
(Note this reaction is an in situ source of oxygen which can subsequently oxidize hydrogen sulfide).

Hydrogen sulfide may also form via pure abiotic equilibrium phase chemical processes, such as:

$CaSO_4$ + CO_2 + $\mathbf{3H_2S}$ $\leftrightarrow$ $CaCO_3$ + $3H_2O$ + $\mathbf{2S_{2(s)}}$

Figure 4.3 illustrates an activity diagram for this process.

Figure 4.3



4.3 DIAGENESIS

Biochemical driven process are important for the creation of the regional groundwater flow paths that create Type 3 ROZs Biodegradation of petroleum hydrocarbons generates carbon dioxide, which in turn has effect on carbonate mineralogy. In the San Andres carbonate system anhydrite is converted to calcite. In an iron rich clastic system ferric iron cement can be removed increasing pore space, permeability and pore throat size.

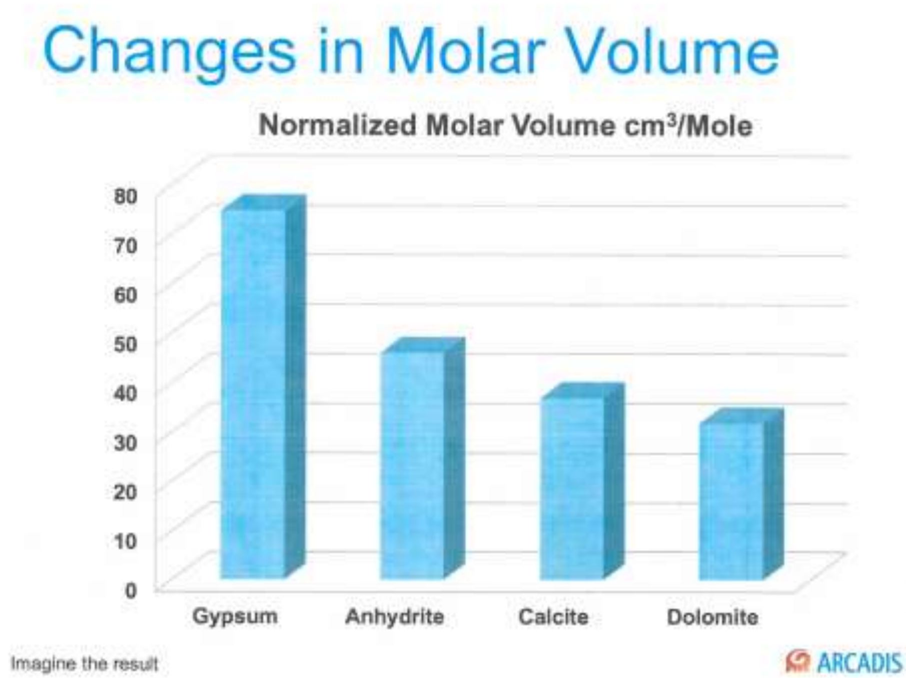
In all cases the cell walls of microbes have functional groups with a negative charge, which allows for preferential scavenging of metabolically important positively charged magnesium ions. Similar ion exchange chemistry is associated with the biofilms produced by microbial activity. In addition the generation of carboxyl groups on partially biodegraded hydrocarbon species also provides negative ion exchange sites. The microbes, biofilms and hydrocarbons tend to coat mineral surfaces in the geologic matrix. The concentration of magnesium associated with the ion scavenging at those mineral surfaces stimulates the formation of dolomite. In carbonate systems petroleum is almost ubiquitously associated with dolomite. The entire process often enhances porosity and permeability as follows:

- Gypsum – $CaSO_4 \cdot 2H_2O$
  - Molar Volume 74.7 cm^3/Mole
- Anhydrite - $CaSO_4$
  - Molar Volume 46.0 cm^3/Mole
- Calcite – $CaCO_3$
  - Molar Volume 36.93 cm^3/Mole

    Vs. Dolomite 2X = 73.86 cm^3/Mole
- Dolomite – $CaMg(CO_3)_2$
  - Molar Volume 63.64 cm^3/Mole

Figure 4.4 illustrates the magnitude of the volumetric effects of biological driven diagenetic processes.

Figure 4.4



Specifically the formation of dolomite has also been observed to be induced by abiotic chemical reactions that accelerate crystal growth stimulated by the presence of hydrogen sulfide (Zhang et al, 2012). One important difference in the physiology of archaeal microbes is that their cell wall surface has approximately an order of magnitude more charged carboxyl functional groups than bacteria. It is possible that the carboxyl functional groups in archaeal cells walls along with extracellular polymeric biomaterials dehydrate magnesium ions with further promotes carbonation that leads to dolomite nucleation (Kenward et al, 2013)

Concentrations of dissolved sulfide as low as 7 mg/L can promote the incorporation of Mg^{+2} into the crystal structure of calcite and promote the formation of high magnesium calcite and disordered dolomite. There is a strong tendency for sulfide to be adsorbed onto calcite crystal faces, which may lower the energy barrier that allows Mg^{+2} water complexes to dehydrate on carbonate surfaces undergoing growth (Zhang et al, 2012).

4.4 CONDITIONS THAT PRESERVE RESIDUAL OIL IN ROZS OVER GEOLOGIC TIME FRAMES

Petroleum in a ROZ is subject to biological and physical processes that should induce removal, particularly over geologic time frames. However, empirical experience is showing that significant amounts of petroleum is found in place within ROZs. This discussion is focused on the microbial processes that prevent the complete biodegradation of petroleum in an ROZ and that also create oil wet conditions in an ROZ that prevent complete physical sweeping by regional groundwater flow. The critical result is that petroleum in San Andres ROZs is present at residual concentrations sufficiently high to offer economic development targets using Tertiary EOR techniques such and the injection of carbon dioxide.

4.4.1 Microbial Self Inhibition

For microbes to be active they require water, a carbon source, and electron acceptors such as sulfate. All three of those are provided in ROZs within the San Andres. The reason that the petroleum has not been completely degraded in a system with abundant sulfate is a process termed Microbial Self Inhibition (MSL).

As observed in Permian Basin San Andres carbonates with abundant anhydrite or gypsum available in the geologic matrix this MSL process is what allows economic residual oil concentrations to remain in place for time frames that can be in the tens of millions of years or longer. In one particular San Andres modeling effort, results have shown that water flushing through the modeled ROZs processed the equivalent of 17 to 45 pore volumes (Trentham et al, 2012). Although significant flushing occurred, that quantity is not enough to deplete all the sulfates that are being microbial processed, nor the proximal petroleum. These sulfide induced inhibition conditions also affect all other microbial activity as well, including iron reduction and significantly methanogenesis. Under sulfide driven MSL physical flushing and migration of petroleum does take place. But residual petroleum that is physically retained in the geologic pore space by interfacial wetting forces will undergo very little biodegradation even over geologic time frames.

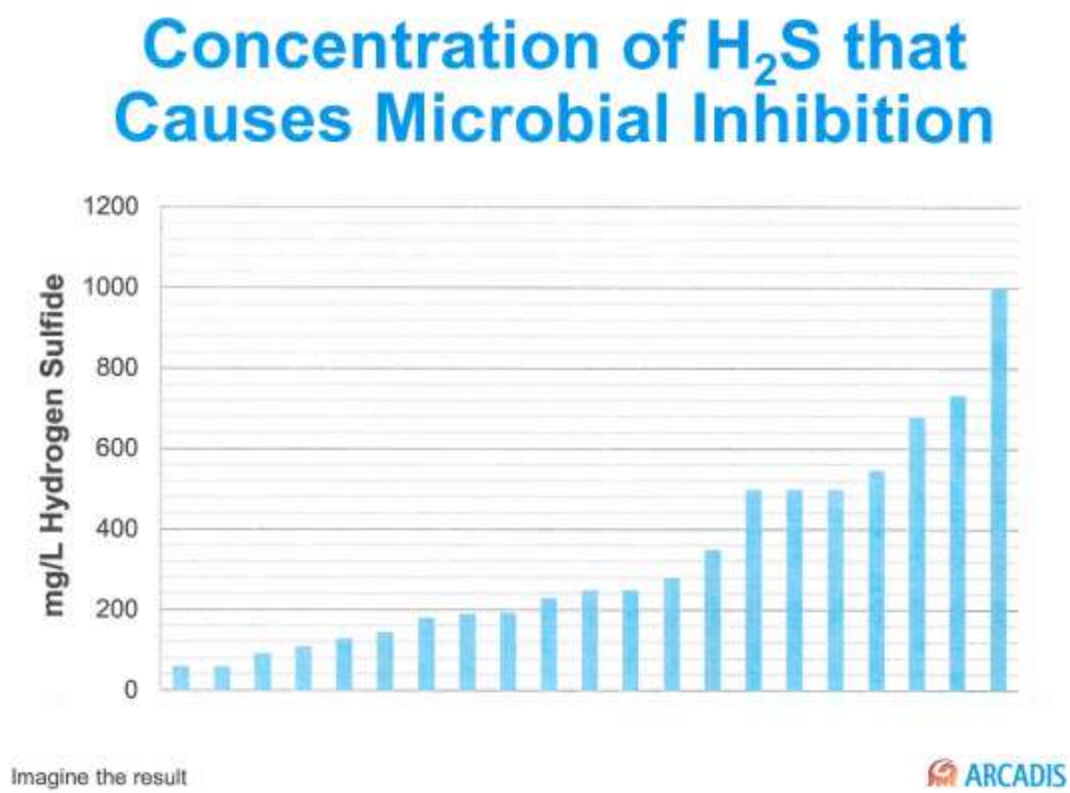
The MSL dynamics in sour oil systems allows for some prediction regarding both ROZs and Transition Zones. Where sulfate is present, MSL can be rapidly established in the presence of petroleum over significant zones of the entire pore volume in the reaction zone of the ROZ. Under conditions were the H_2S concentrates, only limited biodegradation of hydrocarbons takes place, sufficient to allow limited biodegradation of hydrocarbons chains, rings and substituted groups.

Inhibition processes are complex and the precise means of inhibition are complex and an area of continued study. However, it is clear that the effects of hydrogen sulfide do depend on speciation. Hydrogen sulfide undergoes a change in speciation that is dependent on pH. At pH values up to 6.0 the hydrogen sulfide is in the molecular form of H_2S and is undissociated. As the pH increase the dissociated ionic form of hydrogen sulfide HS^- begins to appear. The pH from 6.0 to 9.0 is a zone of transition where both species appear with fraction of molecular hydrogen sulfide declining and the fraction of ionized hydrogen sulfide increasing as the pH increases. In addition, at a pH of 8.5 another dissociation step begins with the monovalent HS^- anion beginning to convert to the divalent S^{2-} anion. The fraction of the S^{2-} anion increases and becomes the dominant sulfide species above a pH of 10.0.

Sulfide inhibition could also be due to permeation of molecular undissociated H_2S into the interior of the microbial cell causing the destruction or proteins causing the cell to become inactive. However, the fact that sulfide inhibition is reversible indicates that mechanism is unlikely to be a dominant one. Energy pathways in microbes are mediated by electron transfer via oxidoreductase enzymes. This includes the dominant microbial pathways that process hydrogen, carbon, nitrogen, oxygen, sulfur and iron. The oxioreductase enzymes with diverse amino acid sequences, however many require transition metals in reactive sites. Transition metals in general will react with sulfide, in particular approximately 50% of all metal-containing oxioreductase use iron (Harel et al, 2014), which readily reacts with sulfide. Hao et al (1996) has reported sulfide inhibition of sulfate reducing microbes likely takes place when any of the sulfide species react with iron in ferredoxin or cytochrome or other compounds essential to biochemical activity in the cell that contain iron or other metal species, ultimately causing electron transport systems in the cell to stop.

Inhibition concentrations reported in the literature are: 64 mg/L to 2059 mg/L for total sulfide; and from 57 to 550 mg/L for undissociated H_2S (Tang et al, 2009). Figure 4.5 illustrates the range of concentration at which sulfide inhibition has been commonly observed.

Figure 4.5



With regards to the inhibition of Methanogenesis in systems with sulfate present the first stage of inhibition is due to simple competition for the organic and inorganic substrates by sulfate reducing microbes (Harada et al., 1994). The cessation of that competitive inhibition takes place at a sulfate concentration near 20 mg/L. Secondary inhibition of all microbes and any associated biogeochemical processes takes place due the inhibition from hydrogen sulfide that is generated by the sulfate reduction process (Chen et al, 2008). For Methanogenesis concentrations of sulfide in the range of 100 to 150 mg/L at a pH of 6.8 have been shown to be severely inhibitory (Speece, 1983) (Paula and Foresti, 2009). In the pH range of 6.4 to 7.2 50% inhibition due to free hydrogen sulfide was found to take place at a concentration of 250 mg/L sulfide (Koster et al, 1986)

Under conditions where sulfate is not present, volatile hydrocarbons present in oil that has not undergone biodegradation inhibit but do not totally halt the biodegradation of alkanes by methanogeneisis (Sherry et al, 2014). This means that given the absence of sulfate there will be a biogeochemical reaction zone from the oil water contact to the zone where the oil concentrations are high enough to induce inhibition due to the volatiles.

4.4.1.1 Effect of Physical Chemistry in ROZs on MSL Processes

In an oil water system the general trend for the equilibrium concentrations of hydrogen sulfide in the oil and water phases is in the range of 3 to 1, i.e. 30 mg/kg of H_2S in the formation water will be in equilibrium with 100 mg/Kg in the oil. If there is a free gas phase the concentration of H_2S in the gas may be 2 orders of magnitude (100X) higher than in oil, for example 100 mg/kg of H_2S in the oil can be in equilibrium with 10,000 mg/Kg of H_2S in the gas (Dean et al, 1993). Assuming a limitation of 200 mg/Kg of sulfide within the bioactive portion of residual oil zone pore space would yield an H_2S concentration of 600 mg/Kg in the oil and 60,000 mg/Kg in the gas phase. That is the physical chemistry that is behind the percent concentrations of hydrogen sulfide often seen in sour production gas.

In general hydrogen sulfide is more soluble in organic compounds than it is in water, with organic solubility increasing with aromatic content and decreasing with paraffin content or polar constituents. Heavier aromatic crudes have a potentially higher solubility that lighter paraffinic crude (Eden et al, 1993). Petroleum exhibits a high degree of compositional character; subsequently each oil will have a unique hydrogen sulfide solubility profile. That potentially can be characterized by detailed compositional testing, but realistically is best determined empirically.

Henry's constant is an expression of ratio of the equilibrium concentration of a gas between a liquid phase and the gas phase at a given temperature and pressure. The Henry's constant for hydrogen sulfide in water is more that an order of magnitude less than the Henry's constant in oil. An example using North Sea crude oil and formation water at 70ºC has a Henry's constant of 17 for water and 549 for oil. That means that there is a much greater tendency for hydrogen sulfide to out gas to higher molar concentrations in the gas phase from oil compared to water (Eden et al, 1993).

The San Andres Formation is relatively iron poor. However, in formations that contain iron, such a clastics with iron oxide cements, hydrogen sulfide will react with available iron to form iron sulfides (Ligtheim et al, 1991). This also means that microbial inhibition of sulfate reducing microbes may not take place and the biological processing of the petroleum will continue. There will be a stoichiometric relationship between hydrogen sulfide removed from the system and petroleum consumed. Potentially this means that residual oil concentrations in iron rich clastics may be lower that those found in iron poor carbonates.

4.5 WETTABILITY

Wettability can be a complex process. However the conditions of the water solution such as pH, ionic strength, and concentration of surface-active dissolved species, may affect the interfacial tension and subsequently wettability. Organic acids can partition into the aqueous phase or adjacent organic liquid phase, effecting pH. Those factors all in turn affect physical transport in the pore space (Lord et al, 1997).

Petroleum asphaltenes and resins make up a dispersed phase with saturates such as alkanes and aromatics composing the liquid continuous phase. Asphaltenes are among the most polar hydrocarbons in petroleum due the presence of sulfur, oxygen, nitrogen and metals in their heteroatomic structure. The less symmetrically the positive and negative charge distribution, the greater the permanent dipole moment (Lithasky and Ayunyaev, 2010).
The oil wet portions of carbonate reservoirs originate due to the adsorption of carboxylyate molecules that diffuse from the petroleum to positive sites attributable to calcium sites on the surface of carbonate. Subsequent destabilization of the water film and bulk petroleum adsorption is promoted by Van der Walls and electrostatic attraction between the positive calcite/water surface and the negative water/petroleum interfaces (Legens et al, 1998).

Unlike apolar molecules, small polar organic compounds can easily enter the dissolved phase and penetrate through thin water films on mineral surfaces to be adsorbed on to those surfaces. Initial adsorption of polar organics at low concentrations can cause significant changes in the wettability of that mineral surface by allowing the subsequent adsorption of apolar organic molecules. The process has two essential stages with initial low level adsorption of small polar organic molecules on to the mineral surface followed by co-adsorption of apolar organic compounds. This displaces the water film and makes the formally water wet mineral surface into an oil wet surface (van Durin and Larter, 2001).

From and empirical perspective testing of cores has shown that petroleum recovery decreases as the concentration of water extractable acidic material increases in the petroleum (making an oil wet system). Water wettability was lower in cores that contained petroleum with only water extractable acids. The presence of water extractable acids negated any wettability modification from lowering the TDS from 66 to 33 grams per liter in core flooding fluids (Fathi et al, 2011). Lastly, in sandstones the same process of adsorption of bulk organic molecules to "sticky anchor points" represented by early adsorption of lighter polar species takes place (Mathiesen et al, 2014).

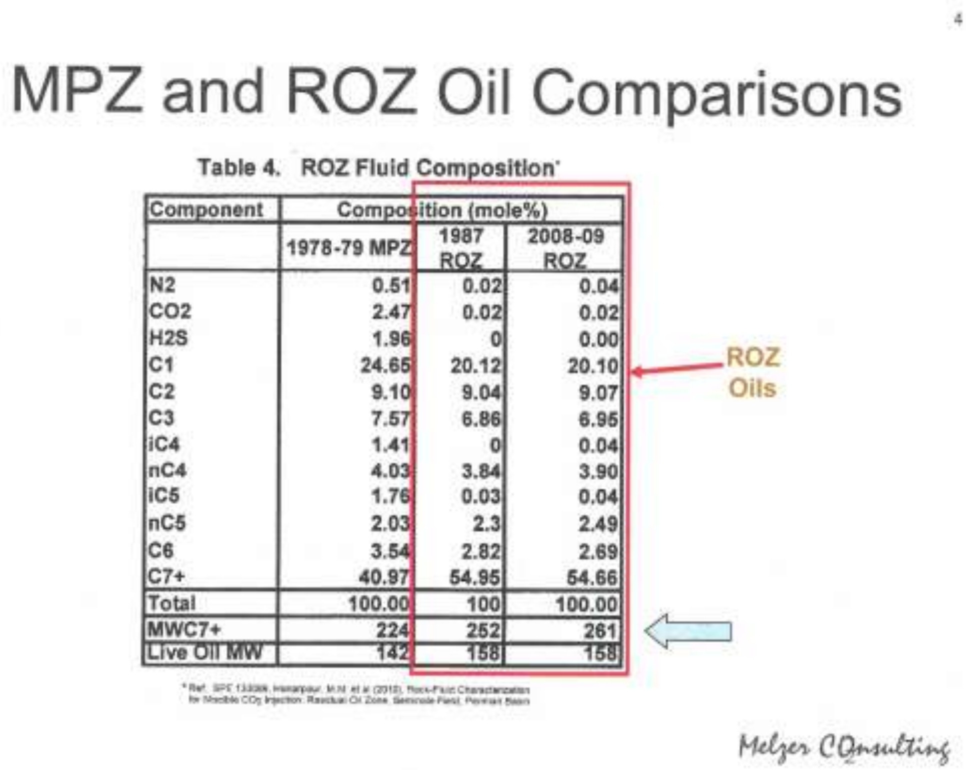
4.6 BIOCHEMICAL PROCESSING OF PETROLEUM IN ROZS

Biodegradation by oxidative pathways of organic species such as n-alkanes takes place in the dissolved phase. The biodegradation process proceeds through a sequence of reactions that produce intermediate degradation daughter products that include alkenes, alcohols, ketones, and carboxylic acids (Sewald, 2001). The general conception is that only methane is produced by biogenic processes. However, the production of C2 and C3 hydrocarbons does take place through microbial processing of petroleum (Hinrichs et al, 2006).

Historically it was thought that n-alkanes were subject to biodegradation and iso-alkanes were recalcitrant. However, those observations were often based on laboratory studies with a limited number of actual conditions that likely did not include all indigenous microbial populations. A key element is the relatively short times frames of those studies. Recent published literature has shown preferential degradation of iso-alkanes under sulfate reducing (Hasinger, et al, 2012) and methanogenic conditions (Siddique et al, 2015). Exhibit 4.4

illustrates the effect on iso-alkanes under sulfate reducing conditions observed in a Permian Basin San Andres ROZ.

Exhibit 4.4



MPZ and ROZ Oil Comparisons

Table 4. ROZ Fluid Composition*

Component	Composition (mole%)		
	1978-79 MPZ	1987 ROZ	2008-09 ROZ
N2	0.51	0.02	0.04
CO2	2.47	0.02	0.02
H2S	1.96	0	0.00
C1	24.65	20.12	20.10
C2	9.10	9.04	9.07
C3	7.57	6.86	6.95
iC4	1.41	0	0.04
nC4	4.03	3.84	3.90
iC5	1.76	0.03	0.04
nC5	2.03	2.3	2.49
C6	3.54	2.82	2.69
C7+	40.97	54.95	54.66
Total	100.00	100	100.00
MWC7+	224	252	261
Live Oil MW	142	158	158

Microbial sulfate reduction is most common in geologic settings in a temperature range of 0 to 80°C. There are hyperthermophilic sulfate reducers, but are rare and uncommon in geologic settings that provide other conditions required for microbial sulfate reduction. The most common reaction products of sulfate reduction of petroleum hydrocarbons are organic acids, and other products such as alcohols and ketones. Thermal Sulfate Reduction TSR begins at temperatures ranging from 100 to 140°C, with rare instances on initiation in the range of 160 to 180°C (Machel 1998). The common reaction products of TSR processing of petroleum include iso and n-alkanes, and gasoline range cyclic and mono-aromatic species (Machel 1998).

Petroleum that has undergone biodegradation contains low molecular weight organic acids that tend to be dominated by multi-functional molecules. The molecular weight range of these biodegradation reaction products are dominantly in the range of 300 to 500 grams per mole. These acids are more carboxylic and aliphatic compared to petroleum that has not been biodegraded with tend to be phenolic (Barth et al, 2004).

Higher levels of petroleum biodegradation have been observed at the oil water contact of ROZs in the San Andres of the Texas and New Mexico Permian Basin. This includes compositional gradients away from those contacts. Similar relationships of biodegradation and oil water contacts have also been reported in the literature (Head et al, 2003)

Laboratory studies have demonstrated the production of carboxylic acids during the biodegradation of petroleum. Medium molecular weight species are initially and rapidly produced in the C10-C20 range as alkanes were consumed. With further biodegradation the initial carboxylic acids are consumed and the concentration of branched and cyclic carboxylic acids the molecular weights greater than C20 appear as complex mixtures (Watson et al, 2002)

It has been shown that the amount of acids in oil increase with increased extent of biodegradation. This is represented by the Total Acid Number (TAN value). Specifically the acyclic/cyclic aliphatic acid ratio is directly correlated to both the extent of biodegradation and the TAN value (Fafet et al, 2008)

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The Following Table (4.1: Summary of the Geochemistry of Water Produced from the 12-county Area of West Texas) is split into four sub-tables.

Table 4.1a - Summary the Geochemistry of Water Produced from the San Andres Formation in the 12 County Study Area

ID USGS	IDDB	LAT	LONG	FLAT	FLONG	API	STATE	COUNTY	FIELD	FIELD CODE	WELL	WELLTYPE	DATE SAMPLE	METHOD	OPERATOR	FORMATION	DEPTH UPPER	DEPTH LOWER	DEPTH SAMPLE	ELEVATION	SPEC GRAV	RESIS	PH	WGL	TDS	HCO3	Ca	Cl	Fe Tot	K	Mg	Na	SO4	H2S	charge balance
41442	USGSMAIN						TEXAS	ECTOR	GOLDSMITH	48-279176	TXL K #4UT	CONV HC	3/31/1957	WELLHEAD		SAN ANDRES					[illegible]	[illegible]	7		[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]			[illegible]
[illegible]	USGSMAIN	[illegible]	-102.715	32	-102.705	[illegible]	TEXAS	ECTOR	GOLDSMITH	48-279252	[illegible]	CONV HC	11/5/1958	WELLHEAD		SAN ANDRES	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	USGSMAIN	33.0004	-102.758	33.001	-102.827	[illegible]	TEXAS	YOAKUM	WASSON	48-750674	1	CONV HC	1/31/1958	FLOWLINE TO TANK		SAN ANDRES	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	61	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	USGSMAIN	[illegible]	-102.851	[illegible]	-102.745	[illegible]	TEXAS	GAINES	ROBERTSON	[illegible]	HILLANDRATH A	CONV HC		[illegible]		SAN ANDRES	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	USGSMAIN	31.6861	-102.147	31.64	-102.14	[illegible]	TEXAS	MIDLAND	PEGASUS	48-[illegible]	TIPPETT USE	CONV HC	7/23/1952			SAN ANDRES	[illegible]		[illegible]	[illegible]			[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	USGSMAIN			33.001	-102.827		TEXAS	YOAKUM	WASSON	48-750674	W. O. MOORE	CONV HC	4/1/1959	HEATER TREATER		SAN ANDRES					[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	USGSMAIN	31.1264	-102.17			[illegible]	TEXAS	MIDLAND	WILDCAT	48-[illegible]	JUNE TIPPITT #27	CONV HC	4/15/1958	DST		SAN ANDRES	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	USGSMAIN	31.5672	-102.576	[illegible]	-102.5[illegible]	[illegible]	TEXAS	CRANE	C-BAR	48-110175	4	CONV HC	11/5/1958	WELLHEAD		SAN ANDRES	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	USGSMAIN	33.0217	-102.774	33.001	-102.827	[illegible]	TEXAS	YOAKUM	WASSON	48-750674	C. WEBBER B #2	CONV HC	1/31/1959	BRADENHEAD		SAN ANDRES			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	USGSMAIN	33.0285	-102.855	33.001	-102.827	[illegible]	TEXAS	YOAKUM	WASSON	48-750674	CHARLIE ANDERSON	CONV HC	3/29/1952	BRADENHEAD		SAN ANDRES			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	USGSMAIN	33.0374	-102.765	33.001	-102.827	[illegible]	TEXAS	YOAKUM	WASSON	48-750674	N.W.WILLARD A #12	CONV HC	7/28/1950	CASINGHEAD		SAN ANDRES			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	USGSMAIN	33.0374	-102.765	33.001	-102.827	4.2E+12	TEXAS	YOAKUM	WASSON	48-750674	N.W.WILLARD A #2	CONV HC	8/18/1950	CASINGHEAD		SAN ANDRES			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 4.1b - Summary the Geochemistry of Water Produced from the San Andres Formation in the 12 County Study Area (Cont'd)

IDUSGS	IDDB	LAT	LONG	RLAT	RLONG	API	STATE	COUNTY	FIELD	FIELD CODE	WELL	WELLTYPE	DATE SAMPLE	METHOD	OPERATOR	FORMATION	DEPTH UPPER	DEPTH LOWER	DEPTH SAMPLE	ELEVATION	SPEC GRAV	RESIS	PH	MGL	TDS	HCO3	Ca	Cl	FeTot	K	Mg	Na	SO4	H2S	charge balance
22213	USGSMAIN	32.0283	-102.532	32.033	-102.532	4213504	TEXAS	ECTOR	COWDEN,	48466395	BLAKENEY A #7	CONV HC	1/6/1953	SEPARATOR		SAN ANDRES			4173	2890	1.049	0.155	7.4	1	65135	396	3050	37580			996	20077	2858		-0.76795
45258	USGSMAIN			31.886	-102.639		TEXAS	ECTOR	LAWSON	48405458	TXL-B NO 1	CONV HC	5/19/1976		SUN OIL CO	SAN ANDRES	4269	4368			1.053	0.281	7.4	1	20834.57	450.79	721.88	10152			442.67	6396.29	2870.34		0.18769
22249	USGSMAIN	32.2306	-102.624	32.271	-102.712	4200364	TEXAS	ANDREWS	SHAFTER	48647020	M SHEPA RD STR	CONV HC	2/15/1956	WATER LEVEL GLA		SAN ANDRES	4500		4610		1.0421	0.12	8.09	1	61681	1107.76	1868	35275.09			1895.62	17814.7	2697.56		0.125215
22292	USGSMAIN	32.2389	-102.489			4200336	TEXAS	ANDREWS	WEMAC	48756333	T.F. TEAGUE #1	CONV HC		DST		SAN ANDRES PERMIAN			1360		1.016		7.6	1	21100	398	350	12800			93	7460	2690		-0.11755
28933	USGSMAIN	31.7085	-102.222	31.675	-102.217	4232901	TEXAS	MIDLAND	SWEETIE	48492350	JUNE SANDERS 2	CONV HC	4/15/1983			SAN ANDRES	5680	5790	1393	2908	1.042	0.111	6.88	1	69029	273	2972	38281.3		228.63	784.63	21881.42	2698.79		-0.00495
22850	USGSMAIN	32.2306	-102.624	32.271	-102.712	4200364	TEXAS	ANDREWS	SHAFTER	48647020	M SHEPA RD STR	CONV HC	2/6/1956	AT WATER GAUGE		SAN ANDRES	4600		4610		1.0404	0.115	8.08	1	59443	596.23	1628	32841.5			1611.61	17235.03	2708.16		0.109851
20284	USGSMAIN	31.5673	-102.576	31.585	-102.586	4210302	TEXAS	CRANE	C-BAR	48410375	CONNELL #4	CONV HC	9/15/1960	TEST SEPARATOR		SAN ANDRES	3589	3658	3658		1.071	0.092	7.6	1	104189	350.19	7945	58577.2	214.4		4428.15	25852.35	2725.01		0.01182
22147	USGSMAIN	31.6421	-102.524			4210303	TEXAS	CRANE	JORDAN		V. TEXA #5	CONV HC	1/21/1956	MEUHFAD		SAN ANDRES	3370	3558	3558		1.036	0.201	7.1	1	40459	2011	1450	20880			56	12912	2721	934	-3.26551
27203	USGSMAIN			32.852	-102.284		TEXAS	GAINES	ADAIR	48003329	JONES B #4	CONV HC	6/5/1960			SAN ANDRES					1.047	0.116	7.3	1	67140	314.14	4228	38889.77			1847.96	18538.28	2750.47		0.00758
45248	USGSMAIN			31.888	-102.738		TEXAS	ECTOR	TXL	48495323	TXL A USE	CONV HC	12/13/1971	FROM HEATER TRE	SUN OIL CO	SAN ANDRES	4181	4410			1.08		6.7	1	105576.5	221.46	4188	63288.38		426.33	1424.24	24080.45	1734		0.00478
29841	USGSMAIN	32.4102	-101.884			4231700	TEXAS	MARTIN	WILDCAT	48476828	HARRY LESTER #5	CONV HC	8/20/1981			SAN ANDRES	4090	4265	3751	2553	1.054	0.106	6.69	1	18180	1260.17	2541	46714.33		268.77	1690.61	24749.35	2726.71		0.09409
30865	USGSMAIN	32.9981	-102.881	33.001	-102.837	4250101	TEXAS	YOAKUM	WASSON	48750574	ELLIOTT #3	CONV HC	5/29/1981	SEPARATOR		SAN ANDRES			5070	3616	1.132	0.054	7.3	1	221259	493.53	5453	133267			2651.14	76681.06	2921.88		0.01759
42830	USGSMAIN	31.9211	-102.559	31.906	-102.486	4213504	TEXAS	ECTOR	DONNELL	48497188	JOHNSTON #5	CONV HC	5/13/1981	SWAB		SAN ANDRES	4380	4370	4800	2973	1.062	0.076	5.8	1	95280	271.87	2440	58033.2			1108.79	30830.35	2903.66		-1.96787
43447	USGSMAIN			32.913	-102.152		TEXAS	DAWSON	WELCH	48756216	D. D. LATTIMORE	CONV HC	7/1/1958	SEPARATOR		SAN ANDRES	4916				1.059	0.094	7.5	1	80496	683	3880	46200			1501	24749	2818		-0.07492
22004	USGSMAIN	31.8677	-102.405	31.889	-102.441	4213501	TEXAS	ECTOR	FOSTER	48452000	BAGLEY #5	CONV HC	8/27/1959	MEUHFAD		SAN ANDRES			4395		1.02	0.171	6.1	1	44695	1209	2850	24000			-1	13509.29	2830		-0.06088
41275	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48750574	KELLER #9	CONV HC	1/24/1956	MEUHFAD		SAN ANDRES	4973	5201			1.1204	0.078	6.3	1	179928	800	3000	106800			1355	64916	2963	76	-0.03123
42766	USGSMAIN	31.8282	-102.421	31.889	-102.441	4213506	TEXAS	ECTOR	FOSTER	48452000	J E WITCHER NO 1	CONV HC	1/25/1978	MEUHFAD	SUN PRODU	SAN ANDRES			4110	2922	1.0204	0.222	8.4	1	26668.35	633.51	1510	12867.24			450	7755.04	2877.55		0.29486
29826	USGSMAIN	33.1091	-102.319			4244500	TEXAS	TERRY			SHELL OIL-FLOYD	CONV HC	6/2/1957			SAN ANDRES	5580	5684	1355		1.141	0.047	6.38	1	215830	779.3	4036	127841.2			1884.93	78207.43	2877.6		-0.02084
22426	USGSMAIN	32.0126	-102.757	32	-102.705	4213505	TEXAS	ECTOR	GOLDSMIT	48479052	RUMSEY D-1	CONV HC	5/19/1951	TANK		SAN ANDRES			4318	3249	1.118	0.06	7	1	187414	385.24	11459	114571.5			3391	52544.89	2877.73		0.01824
22174	USGSMAIN	31.29	-102.614	31.421	-102.549	4210302	TEXAS	CRANE	SAND HILL	48406260	BARNSLEY "C" #6	CONV HC	2/13/1961	MEUHFAD		SAN ANDRES			4345		1.085	0.083	8.1	1	114080	750	390	68000			60	44130	2880		0.00442
45296	USGSMAIN			31.889	-102.441		TEXAS	ECTOR	FOSTER	48452000	FOSTER JOHNSON	CONV HC	1/26/1970		SUN OIL CO	SAN ANDRES	4300				1.055		6.6	1	92099	2850.4	2864	54016			794.42	30101.5	2890.15		-2.67168
28091	USGSMAIN						TEXAS	YOAKUM			C. A. HUDSON	CONV HC	7/14/1964	PRODUCED		SAN ANDRES	4300				1.125	0.057	6.97	1	191650	587	4000	115100		479	2285	68740	2886		0.00855
27184	USGSMAIN			32.852	-102.284		TEXAS	TERRY	ADAIR	48003329	JONES B #6	CONV HC	11/5/1962	SEPARATOR		SAN ANDRES					1.043		7.6	1	40791	655	1284	24508			1147	14436	2887		0.00452
42705	USGSMAIN			31.259	-102.259		TEXAS	CRANE	EPPENAUE	48426781	HOLB 1	CONV HC	9/4/1962			SAN ANDRES	2821	2117			1.058	0.08	6.8	1	70180	1613.29	2834	41050.4			1540.45	19653.8	2888.91		-3.65787
29943	USGSMAIN	31.9289	-102.489			4213503	TEXAS	ECTOR	SAN ANDR	48627900	L.L. JOHNSON #1	CONV HC	7/5/1957			SAN ANDRES			4341	3010	1.067	0.087	6.15	1	93500	122.71	5346	55814.17		212.33	2682.12	24058.67	2900.11		0.09104
27204	USGSMAIN			32.852	-102.284		TEXAS	GAINES	ADAIR	48003329	JONES B #4	CONV HC	6/5/1960			SAN ANDRES					1.047	0.116	7.2	1	67589	1031.19	4218	38895			2089.81	18688.77	2907.53		0.78216
45215	USGSMAIN			32	-102.705		TEXAS	ECTOR	E GOLDSM	48479052	E GOLDSMITH WI	CONV HC	1/25/1978	HEATER TREATER	SUN PRODU	SAN ANDRES					1.0579	0.096	8.1	1	79990.84	660.27	2818	45608.52			936.15	25550.76	2951.36		0.08035
45288	USGSMAIN			32	-102.705		TEXAS	ECTOR	EAST GOL	48479052	E GBAU23-1	CONV HC	4/4/1978		SUN OIL CO	SAN ANDRES	4343	4273			1.0504	0.121	7.8	1	72519.6	804.61	1901	41905.92	7.25		671.21	25314.84	2951.32		-0.00881
28845	USGSMAIN						TEXAS	YOAKUM			WASSON ODC UN	CONV HC	2/22/1970	MEUHFAD		SAN ANDRES					1.045	0.119	7.4	1	60825	1347	2420	33900			810	19519	3000		-0.01099
24001	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48750574	MOORE LEASE	CONV HC	5/3/1956			SAN ANDRES					1.136	0.055	7.4	1	201185	366	3040	120800	11		1224	73945	3005		-0.01244
45210	USGSMAIN			32	-102.705		TEXAS	ECTOR	E GOLDSM	48479052	E GOLDSMITH 13-2	CONV HC	2/12/1978	MEUHFAD	SUN OIL CO	SAN ANDRES	4159	4190			1.0179	0.325	7.6	1	25781.27	622.46	1384	12621.96			447.88	7491.74	3012.98		-0.05057
22466	USGSMAIN	33.0092	-102.884	33.001	-102.837	4250102	TEXAS	YOAKUM	WASSON	48750574	WILLARD A#9	CONV HC	6/1/1952	SEPARATOR		SAN ANDRES			5173	3584	1.143	0.052	7.3	1	209823	497	3196	122154			3179	71417	3020		0.01099
43488	USGSMAIN			31.749	-102.442		TEXAS	ECTOR	COWDEN,	48466267	EDWARDS #1	CONV HC	8/18/1960			SAN ANDRES					1.065		6.8	1	97537	571.91	3483	57836			1127.42	31374.51	3024.6		-2.21279
27142	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48750574	KELLER 16	CONV HC	7/18/1952	MEUHFAD		SAN ANDRES					1.122	0.055	6.2	1	187658	391	2966	108806	36		905	66859	3035		0.01021
22519	USGSMAIN	32.0292	-102.584	32.033	-102.532	4213504	TEXAS	ECTOR	COWDEN,	48466395	BLAKENEY C #6	CONV HC	11/6/1953	SEPARATOR		SAN ANDRES	5345	5375	5360	3222	1.04	0.102	7.2	1	69147	276	2612	39715			1022	23215	3047		1.60258
22197	USGSMAIN	32.8801	-102.744	32.872	-102.746	4216502	TEXAS	GAINES	DOC	48616451	#2 G BRHOLTNER	CONV HC				SAN ANDRES	5506	5543	5507	3448	1.032	0.193	7	1	39900	48	1650	23508			198	12000	3060		-4.99829
27129	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48750574	WHITE #6	CONV HC	1/6/1954	MEUHFAD		SAN ANDRES					1.135	0.054	6.8	1	198971	823	2705	119030			1084	72212	3076		0.01025
30216	USGSMAIN	31.5684	-102.581	31.585	-102.586	4210302	TEXAS	CRANE	C-BAR	48410375	CONNELL #5	CONV HC	1/19/1956	MEUHFAD		SAN ANDRES	3445	3658	3658		1.0606	0.119	6.7	1	84779	366	3050	48800			830	29370.39	3086	5018	-0.03952
28835	USGSMAIN			33.401	-102.898		TEXAS	YOAKUM	LANDON	48400252	C. L. ADAMS	CONV HC	5/16/1963	SEPARATOR		SAN ANDRES	5028	5100			1.166	0.0436	6.2	1	281120	450.08	3078	166383			10227.5	105395.9	3089.9		0.04102
30975	USGSMAIN	32.9447	-102.948			4216500	TEXAS	GAINES	WASSON		A.L. WASSON "31"	CONV HC	12/16/1957	MEUHFAD BLEEDE		SAN ANDRES	5000		4868		1.051	0.109	6.88	1	81000	263	1500	41100		470	2400	22100	3100	1	2.24777
22860	USGSMAIN	32.2306	-102.611	32.271	-102.712	4200300	TEXAS	ANDREWS	SHAFTER	48647020	SHEPARD-STATE	CONV HC	6/11/1954			SAN ANDRES			4800	2198	1.038	0.199	7.2	1	40378	1403	2089	21099			834	11702	3111		-0.00215
22861	USGSMAIN	33.0084	-102.883	33.001	-102.837	4250100	TEXAS	YOAKUM	WASSON	48750574	WILLARD A#7	CONV HC	5/22/1952	SEPARATOR		SAN ANDRES			5200	3586	1.127	0.053	6.8	1	190586	516	3188	112380			1193	68811	3116		0.01007
27111	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48750574	A. B. SMART #8	CONV HC	6/13/1951	MEUHFAD		SAN ANDRES					1.117	0.058	6.9	1	181499	701.48	2701	114466			1420.82	65071.89	3122.07		0.00944
45243	USGSMAIN			32	-102.705		TEXAS	ECTOR	EAST GOL	48479052	E GOLDSMITH SAN	CONV HC	2/6/1980	AT WELLHEAD	SUN PRODU	SAN ANDRES	4212	4206			1.0647	0.096	7.5	1	92803.1	589.84	3058	54512.64	1.06		1330.12	27769.88	3140.87		-0.07948
27141	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48750574	KELLER #16	CONV HC	8/21/1952	MEUHFAD		SAN ANDRES					1.127	0.054	7.2	1	187667	421	3214	111152			1097	68244	3159		0.00988
32450	USGSMAIN	32.9809	-102.897	33.001	-102.837	4250110	TEXAS	YOAKUM	WASSON	48750574	MILLER A #5	CONV HC		SEPARATOR		SAN ANDRES	354	5000	3751	3619	1.131	0.058	6.7	1	200649	809.36	3606	118854			881.2	73002.76	3176.04		0.17567
22883	USGSMAIN	32.2809	-102.579	32.271	-102.712	4200300	TEXAS	ANDREWS	SHAFTER	48647020	#1 B.ELIZABETH M.A	CONV HC		MEUHFAD		SAN ANDRES LA PERMIAN			4815		1.05	0.122	6.9	1	69200	220	3670	38600			1260	21300	3180		-0.57357
32463	USGSMAIN	33.1371	-102.887	33.001	-102.837	4250101	TEXAS	YOAKUM	WASSON	48750574	KELLER #4	CONV HC	6/16/1949	SEPARATOR		SAN ANDRES	5135	5341	5324	3724	1.13	0.056	6.7	1	216495	1109.66	4864	130213.4			439.57	76577.94	3181.03		0.09307
32258	USGSMAIN	32.7492	-102.707	32.756	-102.697	4216500	TEXAS	GAINES	SEMINOLE	48649266	T.S. RILEY B 8	CONV HC	3/15/1958	MEUHFAD		SAN ANDRES	5350		5355		1.025	0.284	7.1	1	35478	1684	1770	17700			472	10664	3188		-0.18583
42802	USGSMAIN	33.0189	-102.754	33.001	-102.837	4250130	TEXAS	YOAKUM	WASSON	48750574	WASSON ODC UN	CONV HC	5/27/1974	MEUHFAD	AMOCO PRO	SAN ANDRES	4872	5129	5129	2819	1.019	0.271	7.4	1	25274	525	1160	12300			317	7772	3200		-0.0156
45289	USGSMAIN			31.886	-102.639		TEXAS	ECTOR	LAWSON	48405458	PHILLIPS PARKER	CONV HC	12/15/1978		SUN OIL CO	SAN ANDRES	4287	4413			1.0829	0.097	7.7	1	88840.34	808.44	2847	50893.75			701.36	30081.2	3203.73		-0.00685
24033	USGSMAIN			32.852	-102.284		TEXAS	GAINES	ADAIR	48003329	JONES B #3	CONV HC	7/13/1956	MEUHFAD		SAN ANDRES	4790	4868			1.033	0.202	6.6	1	37003	1657	1220	17870			485	12140	3212	494	-0.21451
41280	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48750574	RUTH BENNETT B 8	CONV HC	7/13/1955	HEATER TREATER		SAN ANDRES					1.1358	0.05	6.8	1	201019	68	2700	114800			2436	68988	3222		-0.03341
22848	USGSMAIN	32.2306	-102.624	32.271	-102.712	4200364	TEXAS	ANDREWS	SHAFTER	48647020	MAGGIE SHEPARD	CONV HC	2/24/1956	WATER DISCHARG		SAN ANDRES	4500		4610		1.0452	0.113	8.03	1	67396	411.85	2779	38739.82			1876.21	20100.42	3235.2		0.21009
45218	USGSMAIN			32	-102.705		TEXAS	ECTOR	E GOLDSM	48479052	E GOLDSMITH STAT	CONV HC	1/25/1978	HEATER TREATER	SUN PRODU	SAN ANDRES					1.0599	0.109	8.5	1	82943.7	549.98	2818	48214.92			851.03	28084.7	3241.89		0.13747
45284	USGSMAIN			32	-102.705		TEXAS	ECTOR	E GOLDSM	48479052	E GOLDSMITH SAN	CONV HC	4/16/1979	MEUHFAD	SUN PRODU	SAN ANDRES	4160	4214			1.06	0.1	7.9	1	88558.85	991.1	2840	50774	1.06		923.26	28574	3293.6		-0.04129
43412	USGSMAIN			32.852	-102.284		TEXAS	GAINES	ADAIR	48003329	JONES A #3	CONV HC	1/23/1956	MEUHFAD		SAN ANDRES			4860		1.0279	0.171	8.4	1	34741	1203	1340	19880			847	17539	3346	647	-0.14279
45230	USGSMAIN			32	-102.705		TEXAS	ECTOR	E GOLDSM	48479052	E GOLDSMITH SAN	CONV HC	10/1/1978	MEUHFAD	SUN PRODU	SAN ANDRES	4380	4300			1.02	0.163	7	1	30610.09	1287.5	1267	17182	1.06		328.42	16377	3354.8		-0.10054
46854	USGSMAIN	32.3889	-102.77	32.384	-102.808	4200364	TEXAS	ANDREWS	FULLERTO	48425999	UNIV 8 #2	CONV HC	10/22/1974	MEUHFAD	SUN OIL CO	SAN ANDRES	4440	4514	7100	3260	1.0442	0.137	7.8	1	65228.76	810.04	2861	36759.36			704.9	21094.88	3358.31		0.10642
41159	USGSMAIN			32.465	-102.572		TEXAS	ANDREWS	MEANS	48484296	J. S. MEANS F LEAS	CONV HC	2/17/1956	TREATER		SAN ANDRES	4650				1.019	0.244	7.15	1	32208	1367.5	1317	15702.79			395.37	9996.99	3358.76		-0.0074
41278	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48750574	SMART BATT #2	CONV HC	7/13/1956	TREATER		SAN ANDRES					1.112	0.058	7.5	1	171736	367	2780	101450			840	62465	3379		0.40752
45255	USGSMAIN			32	-102.705		TEXAS	ECTOR	SAN ANDR	48479052	EAST GOLDSMITH	CONV HC	2/1/1977	HEATER TREATER	SUN PRODU	SAN ANDRES	4300	4300			1.0616		7.9	1	87779.45	1104.06	3152	50307.52			884.42	29090.35	3380.34		0.01233
30974	USGSMAIN	32.9447	-102.948			4216500	TEXAS	GAINES	WASSON		A.L. WASSON "31"	CONV HC	12/20/1957	MEUHFAD BLEEDE		SAN ANDRES	5000		4868		1.055	0.101	7.1	1	90000	1000	2600	46800		550	2400	24000	3400	2	0.04956
27133	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48750574	MILLER 9-4	CONV HC	6/12/1951	MEUHFAD		SAN ANDRES					1.13	0.047	6.9	1	217386	327.71	3323	129425.7			1298.37	79430.3	3403.25		0.00965
32465	USGSMAIN	33.0091	-102.889	33.001	-102.837	4250100	TEXAS	YOAKUM	WASSON	48750574	WILLARD A#10	CONV HC	5/28/1951	SEPARATOR		SAN ANDRES			5173	3575	1.126	0.052	7.2	1	216030	710.51	3659	128587.6			1422.14	78251.58	3403.21		0.01011
32459	USGSMAIN	32.9781	-102.889	33.001	-102.837	4250101	TEXAS	YOAKUM	WASSON	48750574	L. DOWELL #1	CONV HC	6/12/1951	MEUHFAD WALL		SAN ANDRES	5689	5680	5026	3618	1.115	0.058	7.4	1	186659	400	3585	98883			1009	57460	3312		0.00931
32446	USGSMAIN	33.1512	-102.884	33.001	-102.837	4250110	TEXAS	YOAKUM	WASSON	48750574	MOORE #3	CONV HC	6/6/1951	SEPARATOR		SAN ANDRES					1.136	0.05	7.2	1	205116	215	3291	122160			1108	75020	3319		0.01017
45214	USGSMAIN			32	-102.705		TEXAS	ECTOR	EAST GOL	48479052	E GOLDSMITH SAN	CONV HC	2/12/1978	MEUHFAD	SUN OIL CO	SAN ANDRES	4174	4199			1.0209	0.277	7.5	1	29651	1112.78	1460	14994.69			403.26	8892.04	3317.88		0.04686
32460	USGSMAIN	33.0084	-102.883	33.001	-102.837	4250100	TEXAS	YOAKUM	WASSON	48750574	WILLARD A#7	CONV HC	6/17/1951	SEPARATOR		SAN ANDRES			5200	3586	1.136	0.052	7.1	1	201127	606	2257	120281			1709	73987	3328		0.01084
41160	USGSMAIN			32.465	-102.572		TEXAS	ANDREWS	MEANS	48484296	J. S. MEANS F LEAS	CONV HC	2/1/1956	WATER DISCHARG		SAN ANDRES	4600				1.0212		7.08	1	32112	1279.64	1368	15700.95			417.67	9996.19	3332.09		0.00642

Table 4.1c - Summary the Geochemistry of Water Produced from the San Andres Formation in the 12 County Study Area (Cont'd)

IDUSGS	IODE	LAT	LONG	FLAT	FLONG	API	STATE	COUNTY	FIELD	FIELD CODE	WELL	WELL TYPE	DATE SAMPLE	METHOD	OPERATOR	FORMATION
22455	USGSMAI	32.9908	-102.89	33.001	-102.837	42501026	TEXAS	YOAKUM	WASSON	48-75067	MILLER A-2	CONV/HC	6/12/1951	WELLHEAD		SAN ANDRES
27140	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48-75067	KELLER #15	CONV/HC	8/21/1949	SEPARATOR		SAN ANDRES F
22405	USGSMAI	32.1422	-102.751			42003002	TEXAS	ANDREWS	MARTIN	48-49999	UNIT 11 SEC. 23 #6	CONV/HC	12/9/1949	TANK		SAN ANDRES
22086	USGSMAI	32.1378	-102.758			42003030	TEXAS	ANDREWS	MARTIN	48-49999	UNIV. 11 B #1	CONV/HC	10/1/1958	WELLHEAD		SAN ANDRES
27131	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48-75067	MILLER B-15	CONV/HC	6/11/1951	WELLHEAD		SAN ANDRES
27134	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48-75067	MILLER A-12	CONV/HC	6/20/1951	WELLHEAD		SAN ANDRES
45354	USGSMAIN			32	-102.705		TEXAS	ECTOR	E GOLDSM	48-27905	E GOLDSMITH S A UNIT	CONV/HC	3/9/1979	SEPARATOR	SUN PRODU	SAN ANDRES
22457	USGSMAI	32.9928	-102.895	33.001	-102.837	42501026	TEXAS	YOAKUM	WASSON	48-75067	MILLER A-4	CONV/HC	6/12/1951	WELLHEAD		SAN ANDRES
41796	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48-75067	KELLER #16	CONV/HC	8/17/1949	SEPARATOR		SAN ANDRES PENN
45311	USGSMAIN			32	-102.705		TEXAS	ECTOR	EAST GOL	48-27905	E GOLDSMITH SAN AND	CONV/HC	4/9/1976		SUN OIL CO	SAN ANDRES
45309	USGSMAIN			32	-102.705		TEXAS	ECTOR	E GOLDSM	48-27905	E GOLDSMITH T-26	CONV/HC	2/12/1976	WELLHEAD	SUN OIL CO	SAN ANDRES
22168	USGSMAI	31.4257	-102.551	31.422	-102.549	42103039	TEXAS	CRANE	LEA	48-40636	BARNSLEY C#5	CONV/HC	8/20/1955	SEPARATOR SAMP		SAN ANDRES
22259	USGSMAI	32.752	-102.698	32.758	-102.697	42165000	TEXAS	GAINES	SEMINOLE	48-81999	T S. RILEY B 2	CONV/HC	2/15/1955			SAN ANDRES
42601	USGSMAI	33.0411	-102.775	33.001	-102.837	42501307	TEXAS	YOAKUM	WASSON	48-75067	WASSON ODC UNIT #2	CONV/HC	5/27/1974	WELLHEAD	AMOCO PRO	SAN ANDRES
42630	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48-75067	WASSON ODC UNIT #1	CONV/HC	5/27/1974	WELLHEAD	AMOCO PRO	SAN ANDRES
42597	USGSMAI	33.029	-102.778	33.001	-102.837	42501306	TEXAS	YOAKUM	WASSON	48-75067	WASSON ODC UNIT #4	CONV/HC	5/27/1974	WELLHEAD	AMOCO PRO	SAN ANDRES
41161	USGSMAIN			32.465	-102.572		TEXAS	ANDREWS	MEANS	48-60425	J. S. MEANS G&E	CONV/HC	2/16/1938	TREATER		SAN ANDRES
22458	USGSMAI	33.0091	-102.825	33.001	-102.837	42501019	TEXAS	YOAKUM	WASSON	48-75067	WILLARD A #11	CONV/HC	5/20/1951	SEPARATOR		SAN ANDRES
45288	USGSMAIN			32	-102.705		TEXAS	ECTOR	EAST GOL	48-27905	EAST GOLDSMITH SAN	CONV/HC	3/28/1976	WELLHEAD	SUN PRODU	SAN ANDRES
22462	USGSMAI	33.0094	-102.842	33.001	-102.837	42501002	TEXAS	YOAKUM	WASSON	48-75067	WILLARD A-7	CONV/HC	5/28/1951	SEPARATOR		SAN ANDRES
44591	USGSMAIN			31.886	-102.639		TEXAS	ECTOR	LAWSON	48-40545	J E PARKER A #4	CONV/HC	10/20/1977	WELLHEAD	SUN PRODU	SAN ANDRES
22467	USGSMAI	33.0082	-102.844	33.001	-102.837	42501002	TEXAS	YOAKUM	WASSON	48-75067	WILLARD A #9	CONV/HC	5/20/1951	SEPARATOR		SAN ANDRES
44581	USGSMAIN			31.886	-102.639		TEXAS	ECTOR	LAWSON	48-40545	J E PARKER A #4	CONV/HC	9/13/1977	WELLHEAD	SUN OIL CO	SAN ANDRES
22157	USGSMAI	32.7985	-102.759			42165000	TEXAS	GAINES	SEMINOLE	48-81999	RILEY DREASE	CONV/HC	11/11/1959	HEATER TREATER		SAN ANDRES
24001	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48-75067	MOORE BATT #1	CONV/HC	7/10/1955	SEPARATOR		SAN ANDRES
45228	USGSMAIN			32	-102.705		TEXAS	ECTOR	E GOLDSM	48-27905	E GOLDSMITH SAN AND	CONV/HC	3/28/1979	WELLHEAD	SUN PRODU	SAN ANDRES
45231	USGSMAIN			32	-102.705		TEXAS	ECTOR	E GOLDSM	48-27905	E GOLDSMITH SAN AND	CONV/HC	10/1/1979	WELLHEAD	SUN PRODU	SAN ANDRES
22456	USGSMAI	32.9928	-102.895	33.001	-102.837	42501026	TEXAS	YOAKUM	WASSON	48-75067	MILLER A #4	CONV/HC		SEPARATOR		SAN ANDRES F
27251	USGSMAIN			31.705	-102.614		TEXAS	ECTOR	JORDAN	48-26995	UTEX A #7	CONV/HC	12/28/1949	WELLHEAD		SAN ANDRES
27198	USGSMAIN			32.953	-102.284		TEXAS	GAINES	ADAIR	48-00210	YOUNG LEASE	CONV/HC	5/1/1950	HEATER TREATER		SAN ANDRES
45283	USGSMAIN			32	-102.705		TEXAS	ECTOR	EAST GOL	48-27905	E G S A U 19-3-S	CONV/HC	12/17/1975		SUN OIL CO	SAN ANDRES
44590	USGSMAIN			31.886	-102.639		TEXAS	ECTOR	LAWSON	48-40545	PHILLIPS PARKER WELL	CONV/HC	12/24/1975		SUN OIL CO	SAN ANDRES
42916	USGSMAI	33.0447	-102.756	33.001	-102.837	42501012	TEXAS	YOAKUM	WASSON	48-75067	WASSON ODC UNIT #2	CONV/HC	5/27/1974	WELLHEAD	AMOCO PRO	SAN ANDRES
22451	USGSMAI	32.9906	-102.897	33.001	-102.837	42501102	TEXAS	YOAKUM	WASSON	48-75067	MILLER A-5	CONV/HC	6/12/1951	WELLHEAD		SAN ANDRES
45313	USGSMAIN			32	-102.705		TEXAS	ECTOR	EAST GOL	48-27905	EAST GOLDSMITH-SAN	CONV/HC	2/25/1976	WELLHEAD	SUN OIL CO	SAN ANDRES
27252	USGSMAIN			31.705	-102.614		TEXAS	ECTOR	JORDAN	48-26995	UTEX A-7	CONV/HC	12/19/1950	WELLHEAD		SAN ANDRES
45324	USGSMAIN			32	-102.705		TEXAS	ECTOR	E GOLDSM	48-27905	E GOLDSMITH STAT NO	CONV/HC	1/25/1979	HEATER TREATER	SUN PRODU	SAN ANDRES
45326	USGSMAIN			32	-102.705		TEXAS	ECTOR	EAST GOL	48-27905	E GOLDSMITH SAN AND	CONV/HC	2/6/1980	AT WELLHEAD	SUN PRODU	SAN ANDRES
22449	USGSMAI	32.9942	-102.902	33.001	-102.837	42501102	TEXAS	YOAKUM	WASSON	48-75067	MILLER A-8	CONV/HC	6/12/1951	WELLHEAD		SAN ANDRES
24034	USGSMAIN			32.953	-102.284		TEXAS	GAINES	ADAIR	48-00210	JONES B-2	CONV/HC	7/17/1954			SAN ANDRES
22494	USGSMAI	33.1372	-102.827	33.001	-102.837	42501015	TEXAS	YOAKUM	WASSON	48-75067	KELLER #4	CONV/HC	8/24/1949	SEPARATOR		SAN ANDRES F
22510	USGSMAI	32.7946	-102.749	32.758	-102.697	42165000	TEXAS	GAINES	SEMINOLE	48-81999	T. J. RILEY "D" #7	CONV/HC	2/5/1954	WELLHEAD		SAN ANDRES
24032	USGSMAIN			32.953	-102.284		TEXAS	GAINES	ADAIR	48-00210	JONES B #2	CONV/HC	4/18/1949	SEPARATOR		SAN ANDRES
23940	USGSMAI	31.903	-102.552	31.906	-102.486	42135041	TEXAS	ECTOR	DOWNELL	48-19718	#19 J. L. JOHNSON ED	CONV/HC	5/14/1959	PRODUCED		SAN ANDRES
22464	USGSMAI	33.0088	-102.855	33.001	-102.837	42501002	TEXAS	YOAKUM	WASSON	48-75067	N.W. WILLARD C-4	CONV/HC	6/19/1951	WELLHEAD		SAN ANDRES
44588	USGSMAIN			31.886	-102.639		TEXAS	ECTOR	LAWSON	48-40545	PHILLIPS PARKER NO 5	CONV/HC	11/4/1975		SUN OIL CO	SAN ANDRES
41162	USGSMAIN			32.465	-102.572		TEXAS	ANDREWS	MEANS	48-60425	J. S. MEANS G2	CONV/HC	6/12/1955	DST NO. 2		SAN ANDRES
20189	USGSMAI	32.7988	-102.749	32.758	-102.697	42165002	TEXAS	GAINES	SEMINOLE	48-81999	T S. RILEY "D" #5	CONV/HC	2/25/1954	WELLHEAD - SWAB		SAN ANDRES
20146	USGSMAI	32.6671	-102.285			42165000	TEXAS	GAINES	NOT KNOWN		BURLESON #1	CONV/HC	2/5/1952	DST #3		SAN ANDRES
45221	USGSMAIN			32	-102.705		TEXAS	ECTOR	E GOLDSM	48-27905	E GOLDSMITH SAN AND	CONV/HC	10/1/1979	WELLHEAD	SUN PRODU	SAN ANDRES
27120	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48-75067	WHITE #6	CONV/HC	1/8/1952	WELLHEAD		SAN ANDRES
20115	USGSMAI	32.9367	-102.305	32.953	-102.284	42165000	TEXAS	GAINES	ADAIR	48-00210	ULES #1	CONV/HC	3/1/1950	WELLHEAD		SAN ANDRES
20114	USGSMAI	32.9367	-102.305	32.953	-102.284	42165000	TEXAS	GAINES	ADAIR	48-00210	ULES #1	CONV/HC	2/3/1950	WELLHEAD		SAN ANDRES
45278	USGSMAIN			32	-102.705		TEXAS	ECTOR	EAST GOL	48-27905	E GOLDSMITH SAN AND	CONV/HC	4/12/1976		SUN OIL CO	SAN ANDRES
22448	USGSMAI	32.9942	-102.902	33.001	-102.837	42501102	TEXAS	YOAKUM	WASSON	48-75067	MILLER A #8	CONV/HC		SEPARATOR		SAN ANDRES
45212	USGSMAIN			32	-102.705		TEXAS	ECTOR	EAST GOL	48-27905	EAST GOLDSMITH-SAN	CONV/HC	2/19/1976		SUN OIL CO	SAN ANDRES
24048	USGSMAIN			32.025	-102.78		TEXAS	ECTOR	GOLDSMI	48-27913	J. M. WILLIAMSON LSE	CONV/HC	7/12/1957	STOCK TANK		SAN ANDRES
45229	USGSMAIN			32	-102.705		TEXAS	ECTOR	E GOLDSM	48-27905	E GOLDSMITH SAN AND	CONV/HC	5/29/1979		SUN PRODU	SAN ANDRES
20169	USGSMAI	31.4257	-102.551	31.422	-102.549	42103039	TEXAS	CRANE	LEA	48-40636	BARNSLEY C-5	CONV/HC	8/20/1955	WELLHEAD-SWAB		SAN ANDRES
24051	USGSMAIN						TEXAS	ANDREWS	MARTIN	48-49999	UNIV. 11 - SEC. 2 - #1	CONV/HC	7/20/1955	WELLHEAD		SAN ANDRES
45307	USGSMAIN			32	-102.705		TEXAS	ECTOR	EAST GOL	48-27905	E GOLDSMITH SAN AND	CONV/HC	4/13/1980	WELLHEAD	SUN PRODU	SAN ANDRES
22185	USGSMAI	32.7969	-102.719	32.758	-102.697	42165000	TEXAS	GAINES	SEMINOLE	48-81999	RILEY "C" #2	CONV/HC	8/28/1957	SEPARATOR		SAN ANDRES
27128	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48-75067	HOVENCAMP #6	CONV/HC	6/19/1951	WELLHEAD		SAN ANDRES
22088	USGSMAI	31.5998	-102.6	31.585	-102.588	42103039	TEXAS	CRANE	C-BAR	48-11017	W.K. CONNELL #6	CONV/HC	12/29/1955	STOCK TANK		SAN ANDRES
22101	USGSMAI	32.1674	-102.758			42003004	TEXAS	ANDREWS	MARTIN	48-49999	UNIV. 11 SEC. 11 #2	CONV/HC	9/9/1955	WELL HEAD		SAN ANDRES
41444	USGSMAIN			31.923	-102.746		TEXAS	ECTOR	TXL	48-89512	TXL G #1-C	CONV/HC	10/4/1960			SAN ANDRES
28236	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48-75067	OIL DEVELOPMENT CO	CONV/HC	10/5/1957	TREATER		SAN ANDRES
42600	USGSMAI	33.0147	-102.764	33.001	-102.837	42501306	TEXAS	YOAKUM	WASSON	48-75067	WASSON ODC UNIT #4	CONV/HC	5/27/1974	WELLHEAD	AMOCO PRO	SAN ANDRES
22184	USGSMAI	32.7969	-102.719	32.758	-102.697	42165000	TEXAS	GAINES	SEMINOLE	48-81999	RILEY "C" #2	CONV/HC	8/20/1957	SEPARATOR		SAN ANDRES
42622	USGSMAIN			33.001	-102.837		TEXAS	YOAKUM	WASSON	48-75067	WASSON ODC UNIT #1	CONV/HC	5/27/1974	WELLHEAD	AMOCO PRO	SAN ANDRES
22452	USGSMAI	32.9655	-102.797	33.001	-102.837	42501102	TEXAS	YOAKUM	WASSON	48-75067	HAVENCAMP #4	CONV/HC	6/19/1951	WELLHEAD		SAN ANDRES
45327	USGSMAIN			32	-102.705		TEXAS	ECTOR	EAST GOL	48-27905	E GOLDSMITH SAN AND	CONV/HC	2/6/1980	AT WELLHEAD	SUN PRODU	SAN ANDRES
45308	USGSMAIN			32	-102.705		TEXAS	ECTOR	EAST GOL	48-27905	E GOLDSMITH 18-25	CONV/HC	3/3/1976	WELLHEAD	SUN OIL CO	SAN ANDRES

IDUSGS	DEPTH UPPER	DEPTH LOWER	DEPTH SAMPLE	ELEVATION	SPEC GRAV	RESIS	PH	MGL	TDS	HCO3	Ca	Cl	Fe Tot	K	Mg	Na	SO4	H2S	charge balance
22455					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
27140					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
22405					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
22086					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
27131					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
27134					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
45354					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
22457					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
41796					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
45311					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
45309					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
22168					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
22259					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
42601					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
42630					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
42597					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
41161					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
22458					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
45288					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
22462					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
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22467					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
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24001					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
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42600					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
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45327					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]
45308					[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]

Table 4.1d - Summary the Geochemistry of Water Produced from the San Andres Formation in the 12 County Study Area (Cont'd)

IDUSGS	IDDB	LAT	LONG	FLAT	FLONG	API	STATE	COUNTY	FIELD	FIELD CODE	WELL	WELLTYPE	DATE SAMPLE	METHOD	OPERATOR	FORMATION	DEPTH UPPER	DEPTH LOWER	DEPTH SAMPLE	ELEVATION	SPEC GRAV	RESIS	PH	MGL	TDS	HCO3	Ca	Cl	Fe Tot	K	Mg	Na	SO4	H2S	charge balance
44687	USGSMAIN			[illegible]	-102.639		TEXAS	ECTOR	LAWSON	[illegible]	PHILLIPS PARKER NO	CONV HC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
43411	USGSMAIN			[illegible]	-102.394		TEXAS	GAINES	ADAIR	[illegible]	JONES A#2	CONV HC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
44686	USGSMAIN			[illegible]	-102.639		TEXAS	ECTOR	LAWSON	[illegible]	PHILLIPS PARKER NO	CONV HC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
45326	USGSMAIN			32	-102.705		TEXAS	ECTOR	E GOLDSM	[illegible]	EGOLDSMITH W STA	CONV HC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
32656	USGSMAI	31.5654	-102.594	[illegible]	-102.588	[illegible]	TEXAS	CRANE	C-BAR	[illegible]	W.E. CONNELL B #1	CONV HC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
42621	USGSMAIN			[illegible]	-102.827		TEXAS	YOAKUM	WASSON	[illegible]	WASSON ODC #150	CONV HC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
42915	USGSMAI	[illegible]	-102.738	[illegible]	-102.827	[illegible]	TEXAS	YOAKUM	WASSON	[illegible]	WASSON ODC UNIT	CONV HC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
37253	USGSMAIN			[illegible]	-102.614		TEXAS	ECTOR	JORDAN	[illegible]	UTEX A #1	CONV HC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24561	USGSMAIN			[illegible]	-102.627		TEXAS	YOAKUM	REEVES	[illegible]	DELL B ABBER USE #1	CONV HC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
32216	USGSMAI	[illegible]	-102.744	32	-102.705	[illegible]	TEXAS	ECTOR	GOLDSMIT	[illegible]	RUMSEY C #9	CONV HC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
32774	USGSMAI	[illegible]	-102.688	32	-102.705	[illegible]	TEXAS	ECTOR	GOLDSMIT	[illegible]	DAVID RUMSEY A #1	CONV HC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Chapter 5 – EXPLORING FOR ROZs

Author: R.Trentham

5.1 EXPLORING FOR ROZ's: A CASE STUDY

Exploring for ROZ's is little different than exploring for new field or new pool targets. When all the data is gathered and interpreted, the western margin of the Central Basin Platform can be seen to have considerable ROZ potential. The method employed to evaluate the new field potential of the area resulted in the discovery of two new fields in a study area, but also led to the realization that there are multiple stacked ROZ's in the area. The presence and importance of the ROZ's was not, in 1991, identified. It wasn't until more than a decade later that the ROZ potential was realized.

The western margin of the Central Basin Platform in Ward County is virtually devoid of Permian carbonate production. A 150 sq. mile portion of the western edge, Figure 5.1, is productive from the Yates, Queen, upper Pennsylvanian shelf carbonates and lower Pennsylvanian chert detritals, in multi-million barrel fields. However, until 1991, there were no significant fields producing from the Permian carbonate section on this portion of the western CBP. A review of DST's, cores and core analyses, and IP's have led to the conclusion that the Tubb Carbonate (Lower Clearfork), upper Clearfork, Glorieta, lower San Andres (McKnight, G1 – G4 of Kerans, 2002), and middle San Andres (Judkins, G8 of Kerans) are by-in-large ROZ's with varying quality.

Figure 5.1. ROZ properties Study area, west side of the Central Basin Platform, Ward and Winkler counties.

In the project area, there are 190 wells that penetrated, or partially penetrated the interval between the top of the San Andres thru the base of the Tubb Carbonate (Lower Clearfork). Many of these wells had tested one or more of the intervals prior to 1991, with limited success. In addition, there are ~100 Pennsylvanian wells that drilled thru, and logged, the study interval without testing the Permian.

There were a number of wells that had perfed, acidized, and swabbed and/or attempted to complete multiple zones together in the mistaken belief that the only way to make an economic producer was the try produce the multiple zones together as each zone alone would be un-economic.

An example of this is the #113 W. A. Estes. A well drilled to the Pennsylvanian in 1982, and plugged back in the early 1990's. The well was perfed and acidized in the Judkins from 3936 – 3938', swabbed 64 BW in 2 ½ hours, then perfed and acidized from 3996 – 4000' and swabbed 16 BW, then swabbed dry; the operator perfed the McKnight from 4382 – 4386' (swabbed 2 BO, 2 BW in 2 hrs, then Swabbed dry; the operator then perfed and acidized the Glorieta from 4696 – 4758'. The perfs from all 3 intervals were produced together and recovered 21 BO, 182 BW on the first day. The well was produced/swabbed for 23 days and made 80 BO, 6426 BW. The production on the last day before P&A was 4 BO, 217 BW. The results of wells like the #113 W. A. Estes lead to additional confusion and the belief that none of the zones were prospective. Question about communication behind pipe, and "fracing down to water" were commonly discussed as the reason for the large volumes of produced water

Over a 50 year period from the 1940's to the 1990's there had been DST's and core recovered from a number of wells. In addition, there were a number of attempts to complete wells in one or more of the four zones of interest: the Tubb Carbonate (Lower Clearfork), Glorieta, lower San Andres (G1 – G4 of Kerans, 2002) sometimes referred to as the Holt or McKnight, and middle San Andres interval, referred to as the Judkins.

5.1.1 Examples of Data and Analyses in ROZ's

The following are some examples of the testing of wells drilled prior to the 1991 discovery:

The #513 H. S. A. was an early well drilled 6 miles northeast of the 1991 Glorieta discovery. The Glorieta was DST'd, 4705-4735', and recovered 5' DM; the Glorieta DST, 4805-4888', recovered 180' HGCDM, 60' SWCDM; the Glorieta DST, 4750-4809', recovered 500' G, 5' GCDM; the Glorieta DST, 4936-4989', recovered 35' SWCDM. These DST's had to be based on a drilling break and/or mudlog shows (although the data is not available) and represent tests of the updip intertidal to supratidal environments and the recovery of small amounts of gas is what would be expected. A DST of the lower San Andres McKnight, 4520 - 4615', recovered 100' SWCSM, 190' SW, also what would be expected of the interval in this updip position. A middle San Andres Judkins DST, 4364 - 4384', recovered 40'SGCDM. Again the updip position resulted in poor rescoveries.

The #646 H. S. A. is another early well that is on the downdip nose of the W. A. Estes field. The well was tested in the lower San Andres McKnight interval, 4550 - 4650', and recovered 15' O&GCDM, and 140'GIDP; the well was then DST'd, 4760 - 4870', and recovered

10' FO, 450' Sulfur Water. After the 1991 discovery, the direct offset well to the #646, the #1542 H. S. A., IPP 67 BO, 7 MCF, 55 BW after acid with 1250 gal from 4744 – 4788'.

The #44 W. A. Estes another early well on the southwest flank of the W. A. Estes Field, DST'd the lower San Andres McKnight, 4440 - 4560', and recovered 1350' Salty Sul Wtr, 60'DM, the well was DST'd in the upper Glorieta, 4680 - 4740', and recovered 270' DM/sliSO&G; another Glorieta DST, 4740 - 4800', recovered 360' DM, 60' SO&GCDM. The well was tested in lower Glorieta, 5050 - 5130', and recovered 270' SliO&GCDM.

The #1449 H. S. A. was cored 4575-4695' and review of the core determined that the lower San Andres was in a deeper open marine position with fusulinid wackstones to packstone the dominant facies. A Tubb Carbonate DST, 6220 - 6320', recovered 547' HO&GCM, 15' Oil; a lower Tubb Carbonate DST, 6745 - 6898', recovered GTS 50 min, rec 13 bbl HGCO, 60 bbl SGCFW. However, when perfed, 6865 - 6869' acid w/1500 gal, the well was swabbed and recovered 139 BW, then 165 BW, and the perfs were squeezed. Perf from 6781 - 6784' were acidized w/2000 gal, swabbed 258 BW, and the perfs squeezed. This is an example of the ROZ in the lower Clearfork where good test results do not lead to a successful completion.

The G. W. O. #1218, 8 miles to the northwest of the 1991 discovery DST'd middle San Andres, 3465 - 3525' and rec 3255' sulfur water. This is a "classic" DST of a middle San Andres ROZ in this area.

5.1.2 Case Study

As a result of the impending expiration of the 75 year term on the 48 sq. mile. H. S. A. lease, in the early 1990's, Chevron conducted a 6 month evaluation the potential of the interval from the base of the productive Queen to the top of the productive upper Pennsylvanian shelf carbonates. All available DST, core and log data for the +/- 5000' thick interval was reviewed. Although there were a few scattered wells that had produced some oil from the section, there were no fields in the 100+ square mile study area (including the G. W. O'Brien leases in Ward County, the H. S. A. lease, the E. W. and W. A. Estes, and other smaller associated leases). The +/-5000' thick interval was believed to be of such low value that when the electric logs were scanned and digitized during the 1980's, only the Pennsylvanian and deeper and the Yates and Queen intervals were processed. The interval from the base of the Queen to the top of the Penn was not digitized to save money. As a result, the review project utilized paper copies of logs.

The formation that had garnered the most attention over time was the Glorieta. There were good shows on the available mud logs, and there had been a number of DST's that had recovered small volumes of oil with Drilling Mud, Salt Water or Salty Sulfur Water. In addition, porosity logs thru the Glorieta interval indicated that at a point ~150' below the top of the Glorieta, there was a 100 to 200'' thick zone of good to excellent porosity and good calculated oil saturation, this zone was also known to have excellent mud log shows. Multiple attempted completions in the lower Glorieta, however, had resulted in the production of large volumes of sulfur rich water with little or no oil in all but a few wells.

During the Chevron 6 month study, it was realized that the upper Glorieta was composed of subtidal to supratidal facies and it was this interval that, when DST'd, that produced smaller volumes of oil, gas, and drilling mud or water and that the lower Glorieta, composed of more open marine facies with good porosity and shows would typically produce larger volumes of sulfur water on DST or during an attempted completion. The upper Glorieta, with thinner, less permeable cycles had retained higher oil saturations (>70%) and had not been swept by Mother Nature's Waterflood, while the oil saturation in the lower Glorieta had been flushed to Residual to Waterflood (So=+/-30%) values and represents the ROZ. Updip of the study area, the upper Glorieta intertidal and supratidal facies are neither porous nor permeable, while the lower Glorieta is subtidal to supratidal facies tract and can be productive.

In December 1991, the W. A. Estes # 79, a Pennsylvanian (Strawn) gas well was being considered for plugging. This well was an excellent candidate for a plug back to the Glorieta as the well was located on a northwest trending structural nose. The well was perfed, from 4638 – 4802', and acidized with 7500 gal. No frac was employed to reduce the chance of fracing down into the lower Glorieta ROZ. The well was IP'd for 149 BO, 175 MCF, 81 BW. This well confirmed that the upper Glorieta was productive and indirectly confirmed that the lower Glorieta was an ROZ in this area.

Following the discovery, Chevron monitored the well for over 6 months before drilling an offset as they suspected that, based on other wells in the area, production in the well would rapidly decline or water out. When it did neither, they began a field development program of the W. A. Estes (Holt) Field. Today, there is an active waterflood in the W. A. Estes (Glorieta) Field, which has produced 1,088,637 BO and 1,627 MMCFG. The H. S. A. Field has produced and >1,500,000 BO and 530,000 MCFG.

During the development W. A. Estes (Holt) Field, mudlog shows were commonly reported in the middle San Andres Judkins zone. A number of older Yates or Queen wells in the North Ward Estes field were deepened 1000 to 1500' to test the Judkins. This resulted in the discovery of the H. S. A. (San Andres) field immediately to the northwest of the W. A. Estes (Holt) Field.

5.1.3 Evaluation of IP and Other Data

Twenty six (26) wells have IP's in the upper San Andres, 10 wells are injecting water in the H. S. A. (San Andres) Field, and 11 other wells tested the interval and were squeezed after recovering water. Two examples of the results of DST's that suggest the interval is an ROZ: In the Gulf #319 H.S.A. a DST was taken in the Judkins from 3333 - 3389' which rec 160' GCM w/2% oil; and a second Judkins in the Gulf #319 H.S.A. DST'd from 3880 - 3937 and rec 3700' sulfur water. These two DST's represent the end members of the types of DST response expected for the upper San Andres. The Gas Cut Mud with 2% Oil is an example of a "tite" DST of the intertidal to supratidal facies track. A review of similar responses in DST's from the uppermost Glorieta led directly to the discovery of the W. A. Estes (Holt) field in 1991. Approximately ½ of the Judkins IP's have oil cuts more than 25%, Figure 5.2 and Figure 5.2A, these wells are believed to have been impacted by Mother Nature's Waterflood and have reduced oil saturations.

Thirty two (32) well have now been completed in the lower San Andres McKnight, although some are comingled with the Glorieta. A core taken on the McKnight was invaluable in identifying the interval a predominantly open marine limestone. Twenty (20) wells were DST'd in the McKnight. This interval does not appear to be a high a quality ROZ as the other intervals in the study because of the reservoir is a mix of limestone and dolomite. Twenty three (23) of the thirty two (32) wells had less than 25% oil cut on IP, see Figure 5.2, and Figure 5.2B. This suggests that the McKnight interval, like the Judkins, has been impacted by Mother Nature's Waterflood and has reduced oil saturations.

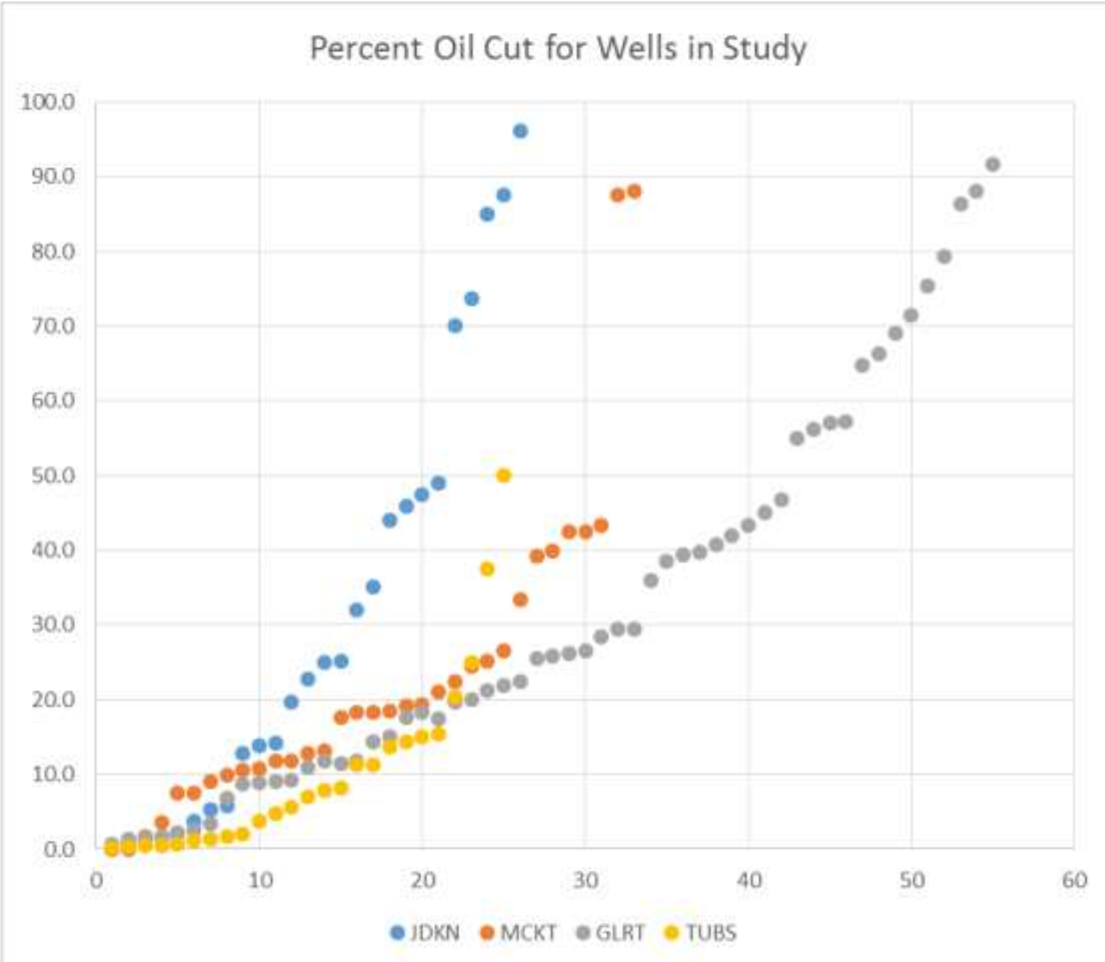

Figure 5.2. Plot of the OIL CUT percent (Y Axis) for the wells completed in the Judkins (Blue), McKnight (Red), Glorieta (Green), and Tubb Carbonate (purple). 25% or less oil cut (Y Axis) is considered to be an ROZ well. Only 2 fields, the Judkins H. S. A. San Andres, and the Glorieta W. A. Estes are presented in the data set and represent the higher oil cut points (>25%).

Forty (40) wells have now been IP'd in the Glorieta, most of the better wells are part of the W. A. Estes Field. In addition, there are 8 injection wells in the W. A. Estes Field, and more than 30 wells that tested the Glorieta but the interval was abandoned without production. Twenty six (26) of the Glorieta producing wells had oil cuts of less than 25%, however, since sixteen (16) of the best wells are in the W. A. Estes Field, more than ½ of the remaining wells had high water cuts, see Figure 5.2, and Figure 5.2C. The Glorieta still remains one of the formations that have the highest ROZ potential in the study area.

There are twenty five (25) Tubb Carbonate producing wells in the study area, With the exception of two wells, all have less than 25% oil cut, see Figure 5.2, and Figure 5.2D. In addition, many of the wells have large total fluid volumes, Table 2. There are also a number of DST's that recovered large volumes of fluid, however the wells if tested were plugged. This leads to the conclusion that the Tubb Carbonate (lower Clearfork) is the most porous ROZ and is second in quality behind the Glorieta.

H. S. A.	1561	IPP 10 BO, 126 MCF, 4591 BW
H. S. A.	1564	IPP 9 BO, 10 MCF, 3133 BW
H. S. A.	876	IPP 13 BO, 88 MCF, 2185 BW
H. S. A.	1164	IPP 25 BO, 24 MCF, 4165 BW

Table 2. IP's for selected Tubb Carbonate completions, North Ward Estes area

Figure 5.2 A – D.Data used to construct the Percent of Oil Cut chart above (Figure 5.2). Figure 5.2 A is Judkins (JDKN) completions and Oil Cuts, Figure 5.2.B is McKnight (MCKT) Completions and Oil Cuts, Figure 5.2.C is Glorieta (GLRT) Copletions and Oil Cuts, Figure 5.2.D is Tubb Catbonate or Lower Clearfork (TUBS) Completions and Oil Cuts

Figure 5.2.A

	WELL #	JUDKINS IP'S	OIL CUT
H. S. A.	1542 I	175 BW	0.0
H. S. A.	876	IPP 2 BO, 20 MCF, 288 BW	0.7
W. A. Estes	80	IPP 5 BO, 1 MCF, 508 BW	1.0
W. A. Estes	113	IPP 3 BO 187 BW	1.6
W. A. Estes	59	IPP 1 BO, 1,MCF, 48 BW	2.0
H. S. A.	875	IP 2 MCF, 51 BW	3.8
W. A. Estes	18	IPP 20 BO, 1 MCF, 351 BW	5.4
H. S. A.	694	IPP 23 BO, 2 MCF, 370 BW	5.9
H. S. A.	694	IPP 53 BO, 2 MCF, 360 BW	12.8
W. A. Estes	141	IPP 15 BO, 3 MCF, 93 BW	13.9
H. S. A.	709	IPP 5 BO, 1 MCF, 30 BW	14.3
W. A. Estes	141	IPP 15 BO, 3 MCF, 61 BW	19.7
H. S. A.	1218	IPP 68 BO, 2 MCF, 230 BW	22.8
H. S. A.	1551W	IPP 14 BO, 2 MCF, 42 BW	25.0
H. S. A.	485	IPP 69 BO, 12 MCF, 205 BW	25.2
H. S. A.	475	IPP 114 BO, 6 MCF, 242 BW	32.0
H. S. A.	3017	IPP 13 BO, 10 MCF, 24 BW	35.1
W. A. Estes	84	IPP 11 BO, 1 MCF, 14 BW	44.0
H. S. A.	1548U	IPP 149 BO, 2, MCF, 176 BW	45.8
H. S. A.	282	IPP 67 BO, 1MCF, 74BW	47.5
H. S. A.	475	IPP 25 BO, 1 MCF, 26 BW	49.0
W. A. Estes	84	IPP 7 BO, 4 MCF, 3 BW	70.0
H. S. A.	1550	IPP 14 BO, 1 MCF, 5 BW	73.7
H. S. A.	280	IPP 259 BE, 5 MCF, 46 BW	84.9
H. S. A.	1218	IPP 56 BO, 3 MCF, 8 BW	87.5
H. S. A.	275	IPP 74 BO 3 MCF, 3 BW	96.1

There were a number of tests in the upper Clearfork, for example, H. S. A. #1018 which DST's the upper Clearfork, 5366-5439, and recovered 1176 'sli GC Sul Wtr with/tr Oil. There were no wells, however, completed as producers in this interval. This interval may also have ROZ potential but would require gathering additional data to determine whether the upper Clearfork is in fact an ROZ.

In summary, the western margin of the Central Basin Platform has considerable ROZ potential when all the data are gathered and interpreted. The method employed to evaluate the new field potential of the area resulted in the discovery of two new fields, but also in the realization that there are multiple stacked ROZ's in the area. The presence and importance of the ROZ's was not, in 1991, identified. It wasn't until more than a decade later that the ROZ potential was realized.

Figure 5.2.B

	WELL#	MCKNIGHT IP	OIL CUT
H. S. A.	1214	IPF 1367 MCF	0.0
G.W.O.	990	IPF 2,337 MCF	0.0
H. S. A.	1552	IPP 4 BO, 40MCF, 224 BW	1.8
W. A. Estes	141	IPP 22BO, 18MCF, 61BW	3.5
H. S. A.	1038	IPP 12 BO, 8 MCF, 148 BW	7.5
H. S. A.	1038	IPP 12 BO, 9 MCF, 148 BW	7.5
H. S. A.	1350	IPP 1 BO, 20 MCF, 10 BW	9.1
W. A. Estes	86	IPP 8 BO, 6 MCF, 72 BW	10.0
H. S. A.	985	IPP 9 BO, 3 MCF, 76 BW	10.6
H. S. A.	875	IPP 10 BO, 82 BW	10.9
E.J.Marston	1	IPP 8 BO, 0 MCF, 60 BW	11.8
H. S. A.	1031	IPP 5 BO, 5 MCF, 37 BW	11.9
H. S. A.	694	IPP 53 BO, 2 MCF, 360 BW	12.8
W. A. Estes	14	IPP 26 BO, 4 MCF, 172 BW	13.1
E.J.Marston	1	IPP 40 BO, 60 MCF, 187 BW	17.6
W. A. Estes	141	IPP 15 BO, 3 MCF, 61 BW	18.3
H. S. A.	1041	IPP 15 BO, 75 MCF, 67 BW	18.3
H. S. A.	3017	IPP 85BO, 47MCF, 375BW	18.5
H. S. A.	1106	IPP 53 BO, 118 MCF, 224 BW	19.1
H. S. A.	3016	IPP 8BO, 20MCF, 365BW	19.4
H. S. A.	1566	4 BO, 15 BW*	21.1
W. A. Estes	59	IPP 20 BO, 18 MCF, 69 BW	22.5
W. A. Estes	13	IPP 39 BO, 25 MCF, 120 BW	24.5
H. S. A.	485	IPP 69 BO, 12 MCF, 205 BW	25.2
H. S. A.	1567	IPP 22 BO, 4 MCF, 598 BW	26.5
W. A. Estes	47	IPP 3 BO, 1 MCF, 6 BW,	33.3
H. S. A.	3015	IPP 78 BO, 37 MCF, 121 BW	39.2
H. S. A.	1037	IPP 70 BO, 0 MCF, 105 BW	40.0
H. S. A.	1548U	IPP 17 BO, 13 MCF, 23 BW	42.5
H. S. A.	1543	IPF 71 BO, 127 MCF, 93 BW	43.3
H. S. A.	1218	IPP 56 BO, 3 MCF, 8 BW	87.5
H. S. A.	1164	IPP 88 BO, 163 MCF, 12 BW	88.0

Figure 5.2.C

WELL	Well #	Glorieta IP	Oil Cut
H. S. A.	876	IPP 2 BO, 20 MCF, 288 BW	0.7
H. S. A.	3014	IPP 4 BO, 20 MCF, 278 BW	1.4
W. A. Estes	113	IPP 3 BO 187 BW	1.6
H. S. A.	1552	IPP 4 BO, 40 MCF, 224 BW	1.8
H. S. A.	3016	IPP 8 BO, 20 MCF, 365 BW	2.1
Richter	119	IPP 13 BO 111 MCF, 490 BW	2.6
H. S. A.	1567	IPP 17 BO, 20 MCF, 473 BW	3.5
Richter	33	IPP 4 BO, 38 MCF, 55 BW	6.8
Richter	36	IPP 20 BO, 56 MCF, 211 BW	8.7
H. S. A.	3015	IPP 21 BO, 20 MCF, 216 BW	8.9
H. S. A.	1350	IPP 1 BO, 20 MCF, 10 BW	9.1
Amer Natl Life	52	IPP 15 BO, 22 MCF, 146 BW	9.3
G.W.O.	1581	IPP 15 BO, 310 MCF, 121 BW	11.0
H. S. A.	1031	IPP 5 BO, 5 MCF, 37 BW	11.9
H. S. A.	1036	IPP 25 BO, 54 MCF, 195 BW	11.4
E.J.Marston	1	IPP 8 BO, 0 MCF, 60 BW	11.8
Richter	76	IPP 33 BO, 90 MCF, 196 BW	14.4
H. S. A.	1186	IPP 212 BO, 242 MCF, 1201 BW	15
E.J.Marston	1	IPP 40 BO, 60 MCF, 187 BW	17.6
H. S. A.	1041	IPP 15 BO, 75 MCF, 67 BW	18.3
Amer Natl Life	53	IPP 7 BO, 28 MCF, 33 BW	17.5
H. S. A.	3017	IPP 40 BO, 20 MCF, 163 BW	19.7
W. A. Estes	44	IPP 5 BO, 3 MCF, 20 BW	20.0
Richter	77	IPP 14 BO, 253 MCF, 52 BW	21.2
W. A. Estes	137	IPP 42 BO, 70 MCF, 150 BW	21.9
W. A. Estes	59	IPP 20 BO, 18 MCF, 69 BW	22.5
W. A. Estes	133	IPP 85 BO, 125 MCF, 247 BW	25.6
Amer Natl Life	53	IPP 7 BO, 28 MCF, 33 BW	25.9
W. A. Estes	141	IPP 22 BO, 55 MCF, 62 BW	26.2
W. A. Estes	141	IPP 22 BO, 18 MCF, 61 BW	26.5
NXS	1	IPP 21 BO, 18 MCF, 53 BW	28.4
E.J.Marston	1	IPP 25 BO, 0 MCF, 60 BW	29.4
H. S. A.	1548	IPP 10 BO, 20 MCF, 24 BW	29.4
Richter	113	IPP 50 BO, 100 MCF, 89 BW	36.0
Richter	94	IPP 35 BO, 70 MCF, 56 BW	38.5
H. S. A.	1106	IPP 61 BO, 220 MCF, 94 BW	39.4
W. A. Estes	139	IPP 85 BO, 120 MCF, 129 BW	39.7
W. A. Estes	135	IPF 89 BO, 100 MCF, 129 BW	40.8
W. A. Estes	138	IPP 29 BO, 30 MCF, 40 BW	42.0
H. S. A.	1543	IPF 71 BO, 127 MCF, 93 BW	43.3
G.W.O.	990	IPF 99 BO, 180 MCF, 121 BW	45.0
G.W.O.	1105	IPF 88 BO, 100 BW	46.8
H. S. A.	1542	IPP 67 BO, 7 MCF, 55 BW	54.9
W. A. Estes	134	IPF 109 BO, 200 MCF, 85 BW	56.2
Walsh & Watts	2	IPP 106 BO, 65 MCF, 80 BW	57.0
Richter	81	IPP 44 BO, 227 MCF, 33 BW	57.1
W. A. Estes	79	IPF 149 BO, 175 MCF, 81 BW	64.8
W. A. Estes	132	IPF 140 BO, 200 MCF, 71 BW	66.4
H. S. A.	664	IPF 165 BO, 180 MCF, 74 BW	69.0

W. A. Estes	131	IPP 30 BO, 40 MCF, 12 BW	71.4
W. A. Estes	136	IPF 135 BO, 240 MCF, 44 BW	75.4
W. A. Estes	129	IPF 127 BO, 107 MCF, 33 BW	79.4
W. A. Estes	130	IPP 89 BO, 70 MCF, 14 BW	86.4
H. S. A.	1164	IPP 88 BO, 163 MCF, 12 BW	88.0
H. S. A.	1213	IPP 11 BO, 150 MCF, 1 BW	91.7

Figure 5.2.D

Lease	Well #	Tubb Carbonate IP	% OIL
H. S. A.	1561	IPP 10 BO, 126 MCF, 4591 BW	0.2
H. S. A.	1564	IPP 9 BO, 10 MCF, 3133 BW	0.3
H. S. A.	876	IPP 13 BO, 88 MCF, 2185 BW	0.6
H. S. A.	1164	IPP 25 BO, 24 MCF, 4165 BW	0.6
H. S. A.	876	IPP 2 BO, 20 MCF, 288 BW	0.7
H. S. A.	1076	IPP 8 BO, 120 MCF, 648 BW	1.2
H. S. A.	1160	IPP 5 BO, 15 MCF, 361 BW	1.4
H. S. A.	1034	SWBD 21 BO, 1108 BW. 5 days	1.8
H. S. A.	1350	IPP 8 BO, 22 MCF, 370 BW	2.1
H. S. A.	1107	IPP 28 BO, 98 MCF, 709 BW	3.8
H. S. A.	1070	IPP 11 BO, 8 MCF, 217 BW	4.8
H. S. A.	1072	IPP18 BO, 25 MCF, 303 BW	5.6
H. S. A.	1560	IPP142 BO, 402 MCF, 1897 BW	7.0
H. S. A.	1552	IPP 23 BO, 45 MCF, 267 BW	7.9
H. S. A.	1363	IPP 21 BO, 50MCF, 235 BW	8.2
H. S. A.	1036	IPP 25 BO, 54 MCF, 195 BW	11.4
H. S. A.	1211	IPP 91 BO, 141 MCF, 709 BW	11.4
H. S. A.	1171	IPP 32 BO, 94 MCF, 201 BW	13.7
H. S. A.	1553	IPP 170 BO, 300 MCF, 1018 BW	14.3
H. S. A.	1186	IPP 212 BO, 242 MCF, 1201 BW	15.0
H. S. A.	1559	IPP 166 BO, 250 MCF, 916 BW	15.3
H. S. A.	1556	IPP 68 BO, 90 MCF, 266 BW	20.4
H. S. A.	1554	IPP 44 BO, 30 MCF, 132 BW	25.0
H. S. A.	1557	IPP 70 BO, 212 MCF, 117 BW	37.4
H.S.A	976	IPP 5 BO, 11 MCF, 5 BW	50.0

5.2 – IDENTIFYING KEY INDICATORS OF ROZS: THE ROZ"COOKBOOK"

Authors: R.Trentham and L.S. Melzer

5.2.1 Step-by-Step Guide

The following step-by-step guide is provided in an attempt to assist a company in an evaluation to determine:

1) whether a Residual Oil Zone (ROZ) might exist beneath their producing field or
2) where a ROZ might exist outside of the limits of a field, and then
3) determine what are the properties of the fluids and rocks within the ROZ that might be exploited with EOR methods.

STEP #1: Gather a Multi-discipline Team for the ROZ Study to Include Talents that Include at a Minimum:

- Reservoir Engineering
- Geoscientist
- Petrophysicist
- Geophysicist

STEP #2: Documenting Existing Data

- For a Field Specific Study
    - Review existing well files for mud logs and sample logs that penetrated below the "established" oil/water contact (hereinafter referred to as the ROZ). Look also for:
        - Drill stem tests (DSTs), water chemistry analyses, any attempted completions within the ROZ interval.
        - Any changes in reservoir mineralogy and connate water chemistry noted between ROZ and main pay zone (MPZ).
        - Wireline logs from the same time frame and estimate the oil saturation (S_o) in the ROZ.

        - Find any surviving cores and/or core reports that might penetrate below the OWC. If found, attempt to estimate the S_o and the thickness of the ROZ. One should not be necessarily dissuaded by S_o values <20% due to the unavoidable loss of oil due to the coring process[3] when utilizing conventional coring methods.
        - Considering the differences between Main Pay and ROZ fluid compositions, pore geometries, oil saturations and mineralogy, attempt to establish an Rw for the ROZ.
        - Collect roughneck and/or cleaned samples for wells drilled thru ROZ.
        - Collect all “anecdotal” information from field, professional and service company personnel, but active and retired of information that pertains to the ROZ.
    - Locate, review and reprocess (if necessary) any seismic data for the field
- For a Field <u>Area</u> Study
    - Incorporate any available field area seismic data into a field, regional or basin-wide structural maps and thru going stratigraphic cross sections of main pay, ROZ, and formation below ROZ., revise if appropriate,
    - Expand field specific study area to look for evidence of “sweep” in the ROZ in regional data.
    - Put together a field area or regional groundwater (flushed fairway {Type 3 ROZ} or vertical sweep {Type 1 or 2 ROZ}) model for the interval of interest.
    - Collect all “anecdotal” information from field, professional and service company personnel, but active and retired of information that pertains to the ROZ.
- For a <u>Basin-wide</u> Study
    - Find and study the latest basement map for the entire Basin in which the Field resides.
    - Find and study the latest basin-wide structural maps on key formation marker tops.

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[3] Core taken at depth under pressure will naturally lose fluid pressure as the core is pulled to the surface and exposed to atmospheric pressures. Any entrained gas in the oil will naturally expand and provide a gas solution drive to expel most of the natural gas and a portion of the liquid. The degree of liquid loss is difficult to estimate but will be a function of entrained gas, viscosity of the oil as well as the porosity and permeability of the rock

- From the literature and above, attempt to reconstruct the basin-wide post depositional, post oil emplacement tectonic history.
- Attempt to construct a regional paleo structural map for the oil emplacement time frame.
- Attempt to reconstruct basin-wide facies maps for the formation(s)/interval(s) of interest. Of special interest are intervals with wide scale lateral continuity.
- Estimate the potential for post emplacement sweep, and, from the basin-wide studies, what tectonic and structural changes have occurred from then to present that would influence paleo trap sweep and, for Type 3 ROZs, OWC tilt.
- Reconstruct the lateral and vertical extent of several paleo entrapments using wells that drilled through the formation(s)/interval(s) of interest.
- Refine facies model map for the Basin to field areas of special interest.
- Tie the above model to the porosity and permeability data (knowing that there are facies/environment of deposition changes diagonally across specific fields).
- Attempt to find a relationship among the field specific fluid properties and rock porosity – permeability - facies that would suggest what intervals/sub-areas exist for optimizing higher ROZ S_o values.

STEP #3: Screen Out Unlikely or Poor ROZ Candidates and Identify Promising Candidates

Some formations or areas within a Basin and even some entire Basins will be poor candidates for ROZ presence. If the anecdotal data from well logs, DSTs, mudlogs etc. do not indicate possible ROZs, the field areas or even entire basins should be eliminated from the need of acquiring new data. Note, however, that it is an unusual basin that does not have tectonic events after hydrocarbon accumulation in the original (paleo) traps.

Any evidence pointing to the presence of ROZs with significant oil saturations (i.e., greater than 25%) should be ranked and advanced to the stage of attempting to gather additional data.

STEP #4: Gathering New Data

After accomplishing the data review and completing mapping of the Roz and Main Pay, there are going to be sub-areas within the field area that have higher than expected ROZ potential. Target it/them first with an eye on an initial "science well" for the best sub-area. If possible, target a location where some primary production might be possible at the top of the ROZ.

- Data to be Acquired <u>with</u> a Newly Drilled Well:
    - Mud Logs from reputable company with lithology, GC components up to C-8, H_2S and CO_2 sensors, fluorescence, and cut. Require mudloggers to note the presence of native sulfur.
    - Whole (conventional) core (sidewall cores are often not useful) with routine core analysis (porosity, permeability, So and Sw) and detailed core descriptions
    - Full, modern suite of wireline logs to include DLL or DIL, Sonic, compensated density/porosity, and pulsed neutron density/porosity and any other special formation particular logs such as PE, spectral gamma etc.
    - Get a formation imaging (FMI) log over the same interval as the core.
    - Run drill stem tests (DST's) or at least repeat formation tests (RFT's) to acquire oil/water/gas samples. Analyze water samples from different depths.
    - Conduct lab analyses of oil and gas samples to reconstruct in-situ oil compositional analysis
    - From formation temperature and compositional analysis, compare against MPZ fluids from nearby fields in the same formation (if possible), estimate ROZ oil saturations, gas/oil ratios (GOR) and minimum miscibility pressures (MMPs).
    - Cross-correlate the mud- and wireline logs and core results, depth correct where necessary.
    - With modern drilling technologies, high quality 10' samples are not possible. Consider using the "Weatherford" technique to leach oil from samples and use UV light to create a relative fluorescence scale.

- Data to be Acquired <u>Without</u> a Newly Drilled Well:

    - Select a promising area that possesses one or more deep wells drilled though the formation(s)/interval(s) of interest.
    - Obtain access to the well or wells to reestablish the nature of the interval of interest in the well (e.g., cased or open hole)
    - Re-enter the well

- Run the above described logs in the case of an open-hole interval
- Acquire a pulse neutron log in the case of a cased interval of interest.
- If a completion is attempted, collect and analyze water samples.

Once in possession of the new data set from new or reentered well(s), reevaluate the sub-area for desirable MPZ and/or ROZ targets and, as desirable targets are identified, identify new sub-area(s) and consider a second “science well” with duplicative data as identified above but substituting the FMI as a proxy for the whole core data set.

STEP #4: Optional Vertical Well Completion

If primary production is promising, select multiple sets of perforations to

1) Acquire ROZ oil/water/gas samples from deep within the ROZ.
    a. Water samples – compare to old pre-water flood MPZ samples if available.
    b. Oil samples, if possible
    c. Gas samples, if possible
    d. Bottom Hole Shut in Pressures
2) Compare above water chemistry to MPZ formation water chemistry from nearby fields and also to modern water flood water chemistry to check for possible vertical cross flow or mixing
3) Evaluate whether to perforate the ROZ in a higher position to check for varying fluid properties with depth into the ROZ.
4) Proceed with the attempt to establish primary production on top of the ROZ and acquire and evaluate fluid properties as above.

5.2.2 Table of Evidence for a ROZ and Explanations

The following table (5.1) lists the various field activities during the drilling and completion of a well with the classic interpretation vs. the interpretation related to a ROZ occurrence and the explanation to that new interpretation.

TABLE 5.1 - Summary of "Classic" Observations of ROZ's and the ROZ-based Revised Interpretation of the Observations

ACTIVITY	EVIDENCE	CLASSIC INTERPRETATION	ROZ INTERPRETATION	ROZ EXPLAINATION
Drilling	Oil on pits	Transition zone/MP remnant oil	Presence of ROZ highly likely	Oil wet reservoir. Oil is released during drilling. Often seen in Roz's
	Drilling Break	Aquifer / No Significance	Good Reservoir	Open marine environment. Good cycles and flow units.
Mud Logging	Cut in samples	Transition Zone / MP Remnant	Oil saturation present	Residual Oil Saturation is present
	Dull gold Fluorescence in samples	Transition Zone / MP Remnant	"Water washed" oil	Indicative of Mother Nature's Waterflood. Reduced Saturation of oil.
	Odor in samples	Transition Zone / MP Remnant	Oil saturation present	Indicative of Mother Nature's Waterflood. Reduced Saturation of oil.
	Gas show	Not expected. From Oil Zone above if present	Oil saturation present	Indicative of Mother Nature's Waterflood. Reduced Saturation of oil.
	"Free" Sulfur crystals	Suggest at or below O/W contact	Mother Natures Waterflood	Result of activity of Sulfate Reducing Bacteria. Indicates Meteoric Derived Flushing.
	Sulfur and Anhydrite	No significance	Mother Natures Waterflood	Result of activity of Sulfate Reducing Bacteria. Indicates Meteoric Derived Flushing.
	Sulfur and Calcite	No significance	Mother Natures Waterflood	Result of activity of Sulfate Reducing Bacteria. Indicates Meteoric Derived Flushing.
DST	Sulfur or Black Sulfur water	Not unusual / No significance	To be Expected	Result of activity of Sulfate Reducing Bacteria. Indicates Meteoric Derived Flushing.
	Salty Sulfur water	Not unusual / No significance	To be Expected	Result of activity of Sulfate Reducing Bacteria. Indicates Meteoric Derived Flushing.
	Lower Salinity than expected	Not unusual / No significance	Meteoric Derived Flushing	Indicative of Mother Nature's Waterflood. Meteoric Derived Flushing
	"Skim" of Oil	Not unusual / No significance	To be Expected. Never significant oil	Oil Wet reservoir. Small amounts of Oil is released during pressure drop.
	Good to Excellent Pressure	Not unusual / No significance	To be Expected	ROZ is not in pressure cmmunicationwith a Main Pay
Logging	Rw different than MP	Not unusual / No significance	ROZ water chemistry different than MP	Rw is different because the meteoric derived sweep is composed of lower salinity water
	So > 30% in calculations	Might be productive	ROZ. Residual to waterflood and MNW	Rw is different because the meteoric derived sweep is composed of lower salinity water
	Different M an N than MP needed	Not unusual / No significance	fabric destructive dolomitization in ROZ only	Rocks have undergone a second diagenetic event
	Excellent Porosity in dolomite	Not unusual / No significance	Open Marine + Sweep associated dolomitization	Thicker open marine cycles and Secondary dolomitization in ROZ during sweep
	"Looks like a *Winner*"	set casing	ROZ can have appearance of producable on completion	ROZ thicker cycles, secondary dolomitization, salinity differences make calculations difficu
Core Analysis	5 - 40% oil saturation	Zones with higher water saturation non-productive	Saturations expected following MNW	Expected. So after Mdeteoric Derived Sweep
	Oil Wet Core	Consider log analysis	Sweep related fabric destructive dolomitization >> Oil wettin	Expected after Sweep related fabric destructive dolomitization
	Open marine facies	Not unusual / No significance	Good Quality reservoir, thick cycles and flow units	ROZ's tend to be found in more open marine settings
	SHR near base and/or top	Suspect oil/water contact(s)/water washing	Water Washing from Meteoric Derived Flushing	Multiple SHR Zone suggest Multiple O/W contact, both Paleo and recent
	Better Porosity and Perm than main pay	Not unusual / No significance	Good Quality reservoir, thick cycles and flow units	ROZ's tend to be found in more open marine settings
	Sulfur Crystals	Diagenesis - no interpretation	Free sulfur often found in ROZ	Conversion by Sulfate reducing bacteria results in free sulfur
	Sulfur and Anhydrite	Diagenesis - no interpretation	Free sulfur often found in ROZ	Conversion by Sulfate reducing bacteria results in free sulfur
	Sulfur and Calcite	Diagenesis - no interpretation	Free sulfur often found in ROZ	Conversion by Sulfate reducing bacteria results in free sulfur
	Spotty Oil Stain	Consider Log Analysis	Intervals with low perm in ROZ	Intervals with low perm in ROZ can have remnat high saturations
	Leached molds	Not unusual / No significance	Leaching during MNW	Leaching during MNW
	Leached Fracture	Not unusual / No significance	Leaching during MNW	Leaching during MNW
	Fabric Destructive dolomite	Not unusual / No significance	Secondary dolomitization in ROZ during sweep	Secondary dolomitization in ROZ during sweep
	Limestone below oil stained interval	Not unusual / No significance	Zone is below Swept ROZ	Zone is below Swept ROZ
Completion	large volumes of fluid (sulfur water)	expect a decrease in water production over time	Large volumes of water cut on IP indicates an ROZ	Swept down to residual to waterflood, good porosity and perm in open marine
	Less than 5% oil	expect an increase in oil production over time	>85% water cut on IP indicateds an ROZ	Swept down to residual to waterflood
	Good Pressure	Not unusual / No significance	ROZ not drained, to be expected	Thinner cycles in MP don't reduce pressure in ROZ
	Lower Salinity than expected	Suspect water flow	Meteoric Derived water	Meteoric Derived water has lower salinity
	Different Scale than in Main Pay	Suspect water flow	Different water chemistry	MNW changes water chemistry significantly

5.2.3 ROZ Properties/Evidence of Presence of a ROZ

The following is an expanded explanation of the data presented in Table 5.1: A Summary of "Classic" Observations of ROZ's and the ROZ based revised Interpretation of the Observations." Much of this data began as "anecdotal" information gleaned from conversations with a number of experienced Permian Basin geologists and engineers along with some personal experiences. These professionals, upon being introduced to the concept of ROZ's, related experiences with ROZ characteristics that were not well understood to them at the time (going back to the 1950's), but which now can be clearly "fit" into the concept of ROZ's. Each of the oil field personnel has had "AHAH" moments where poorly understood data led one to shrug their shoulders and be forced to walk away from a well that "should have been a producer". Those wells were frustrating failures based on our understanding at the time. Most of them would be ROZ CO_2 flood candidates today.

5.2.3.1 Drilling

5.2.3.1.1 Oil on the Pits

Oil on the pits is something expected when drilling thru a main pay or new field discovery, but it is almost counterintuitive when drilling thru a Residual Oil Zone (ROZ). However, since many ROZ's are oil wet and contain, by definition, between 10 -40% oil saturation, the process of drilling actually releases oil from the rock and a sheen of oil will appear on the pits. An example of this is the Gulf #1 N. E. Elida Unit, sec 1, 4 S, 32 E in Roosevelt County. Oil was seen on the pits, and it was expected that this would be a new field discovery, however, when cores were taken and DST's run it was determined that there was insufficient cause to set pipe and attempt to complete. This is a classic response for a GREENFIELD ROZ. In the Gulf #1 N. E. Elida Unit, There was reported stain in samples 3730-4030. Core taken from 3506 – 3565' and recovered dolomite with NO SHOWS, core taken from 3706 – 3765' had a slight show oil in fracs, core was taken from 3880 – 3920' and recovered Limestone, bleeding heavy oil, core recovered from 3908 – 3921' had So= 30% in the bleeding oil interval, the core taken from 3954 – 4012' recovered Limestone with no shows. A DST run from 3702 – 3765' rec 126' Drilling Mud, 819' salty sulfur water. A DST run from 3876 – 3920' recovered 59' Drilling Mud, 84' slight Gas Cut Sulfur Water. A DST run from 4060 - 4250 recovered 45' Drilling Mud. The well was P&A'd without further testing of the San Andres.

5.2.3.1.2 Drilling Break

As ROZ's are often in the deeper, more open marine portions of the San Andres, the intervals tends to have thicker, more porous cycles, cycle sets, and flow units when compared to the thinner more heterogeneous, and less porous cycles and thinner flow units in the Main Pays (MP). The MP's also tend to have a higher proportion of tidal flat facies which drill slower. Therefore, the ROZ's often drill considerably faster than the MP (if present) or the tidal flat capped non-pay above the Greenfield ROZ's.

5.2.3.2 Mudlogging

5.2.3.2.1 Cut In Samples

As with oil on the pits discussion, ROZ's contain, by definition, between 10 -40% oil saturation so it would be logical to assume that there should be oil in samples seen during examination at the well site. The oil may not have the Flash Cut or Streaming Flow seen in main pays, but ROZ will ALWAYS have some demonstrable cut in fresh samples. With the modern drilling technology, describing 10' samples has become virtually impossible. It is important,

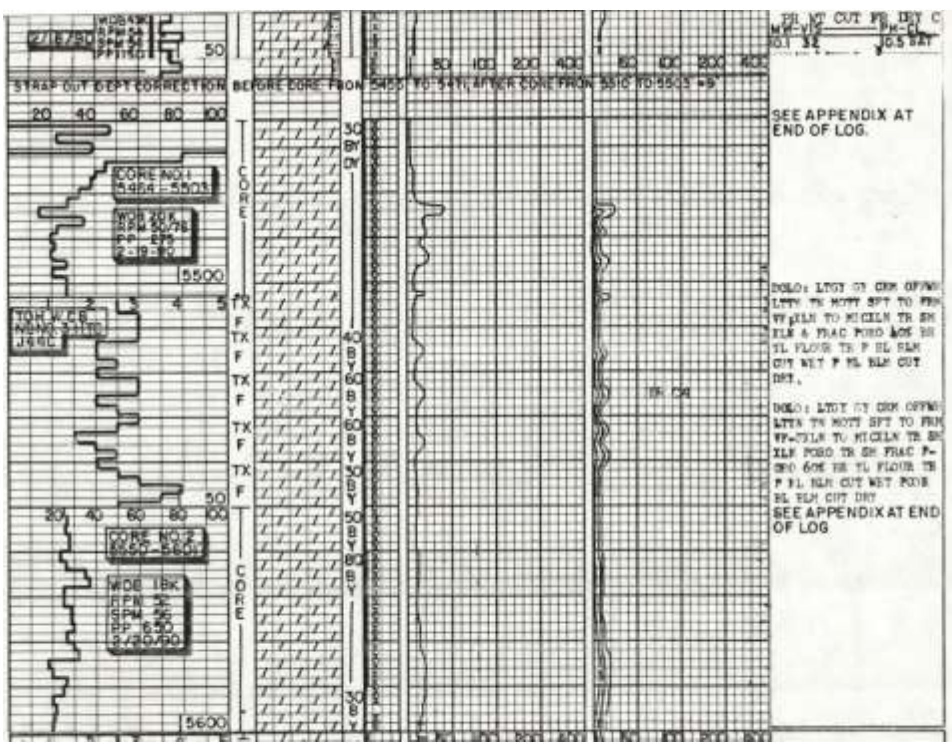


Figure 5.3. Anschutz #1 Keating Mudlog of interval identified as a Greenfield ROZ (5500 – 5550) showing 30 – 60% bright gold fluorescence. The cored intervals above and below were identified as being Greenfield ROZ's.

however, to make an effort to make as complete a description of the samples as possible. As ROZ's can vary from <100' to >300' thick, modern mudlogs may evaluate the ROZ in only 2 to 3 samples. Working with the mudlogger to understand the critical nature of ROZ sampling, and capturing all data for the ROZ interval is important.

5.2.3.2.2 Dull Gold to Bright Yellow Fluorescence in Samples

The Mudlog shown above, Figure 5.3, is from the Anschutz #1 Keating in Gaines County. The well was cored from 5454-5503 and 5550 – 5601' and the presence of a Greenfield ROZ documented in the cored intervals. Between the cored ROZ intervals, the well was drilled and the type of odor, cut and fluorescence expected from a Greenfield ROZ well documented.

As with oil on the pits discussion, ROZ's contain, by definition, between 10 -40% oil saturation so it would be logical to assume that there should be oil in samples seen during examination at the well. Oil may not be as "live" as in the Main Pay, and may not exhibit the "gold" fluorescence thru out as seen where there is >75% oil saturation. Oil in ROZ's has undergone "Mother Nature's Waterflood (MNW), and associated anaerobic bacteria action, and the lighter hydrocarbons may be diminished or absent. This will result in the "Dull" as opposed to "Bright" fluorescence. This is, however, still an indicator of the presence of an ROZ. Make sure the mudlogger records accurately the type and intensity of fluorescence.

5.2.3.2.3 Odor in Samples

Odor will be apparent in fresh "roughneck" samples. As with discussions above, ROZ's contain sufficient oil saturations so that it would be logical to assume that there should be an oil odor in samples seen during examination at the well. The oil may not be as "live" as in the Main Pay, and may not exhibit the sharp odor. The oil in ROZ has undergone MNW and associated anaerobic bacteria action, and there may be a sulfurous odor to the samples as there is most often a salty sulfur or black sulfur connate water associated with the presence of the water washed ROZ. This is also an indicator of the presence of the ROZ. Caution: the sulfur odor may overwhelm the oil odor and be reported as such on the mudlogs. Make sure the mudlogger records these.

5.2.3.2.4 Gas Shows

It might be assumed that because of MNW, there would be little if any gas present in the ROZ and therefore in the roughneck samples. There is demonstrable proof from a number of ROZ's that there is gas in the ROZ, abet at significantly lower volumes than in the MP. GOR's of

500 – 1000 can be expected. This is gas that has migrated into the ROZ after the meteoric sweep had been diminished by the Basin and Range faulting reduced the hydraulic head, see Figure 2.1. The presence of only C1 gas shows is not representative of an ROZ. The presence of significant C2 – C8 gas, however, are expected to be present on the Gas Chromatograph. Make the mudlogger aware that gas shows above C1 are to be expected in the ROZ.

5.2.3.2.5 "Free" Sulfur Crystals

Free sulfur crystals are typically seen only in association with the ROZ. The crystals can range from doubly terminated crystals to botryoidal void filling masses. Because of the bio-geochemical reactions that take place in the ROZ during the meteoric derived sweep, free sulfur can be found in leached fossils, fractures, vugs and interparticle porosity. The Redox based biogenic reaction is**:**

$$CaSO_4 + HC \Rightarrow CaCO_3 + H_2O + H_2S$$

The H_2S is often oxidized back to elemental sulfur (S^0).

The sulfur crystals are typically found within the ROZ but also are present in the water zone/paleo oil/water contact immediately below the ROZ and in the lower MP and in the tight cap above a Greenfield ROZ. Some workers have reported using the presence of native sulfur as an indication that they have reached the oil/water contact in major fields, and cease drilling.

5.2.3.2.6 Sulfur and Anhydrite

Sulfur crystals are typically seen associated with anhydrite in the ROZ. The sulfur and associated with anhydrite crystals can range from terminated crystals to botryoidal and void filling masses, Figure 5.4. Because of the bio-geochemical reactions that take place in the ROZ during the meteoric derived sweep, sulfur and anhydrite can also be found in fractures and vugs. Sulfur and anhydrite associations are typical as void filling minerals.


Figure 5.4. Sulfur and gypsum in hydrated anhydrite nodule in Burlington Resources #51 Reese, Upton County, TX. Note that the nodular anhydrite has been re-hydrated to gypsum in this example from a San Andres reservoir at +/-2350'.

5.2.3.2.7 Sulfur and Calcite

Sulfur crystals are typically seen associated with calcite in the ROZ. The sulfur and calcite crystals can range from terminated crystals to botryoidal and void filling masses, Figure 5.5. Because of the bio-geochemical reactions that take place in the ROZ during the meteoric derived sweep, sulfur and calcite can be found in fractures and vugs. Sulfur and calcite associations are typical as void filling minerals.

Figure 5.5. Sulfur and Calcite in leached void in Chevron H. S. A. #1548, Ward County, TX. Unlike sulfur often associated with anhydrite, sulfur crystals associated with calcite often have well defined crystal faces.

5.2.3.3 Drill Stem Tests (DST's)

5.2.3.3.1 Sulfur and Salty Sulfur Water

Sulfur water, black sulfur water, or salty sulfur water are typical recovered on DST's in ROZ's in both Brownfield and Greenfield reservoirs. As discussed above, the Gulf #1 N. E. Elida Unit, 1 sec 1, 4 S, 32 E in Roosevelt county. Examples of this is a classic response of a GREENFIELD ROZ are now easily recognized. In the Gulf #1 N. E. Elida Unit, A DST run from 3702 -3765' recovered 126' of Drilling Mud, and 819' of **SALTY SULFUR WATER**. A DST run from 3876 – 3920' recovered 59' of Drilling Mud, and 84' slight Gas Cut **SULFUR WATER**. A DST run from 4060 – 4250' rec 45' Drilling Mud, with no water.

For the same reasons that sulfur crystals or sulfur in association with calcite or anhydrite is found in the ROZ (see above), sulfur water is typical of the ROZ even when the ROZ is in a brownfield where the original connate water in the MP was "salt water". Be aware, however, that sometimes the sulfur component of the water is not recorded in the DST report.

5.2.3.3.2 Lower Than Expected Salinity

There have been a number of operators who have reported that the connate water in the ROZ's have lower salinity than that reported in the MP prior to the institution of the waterflood. In addition, there is evidence from two San Andres fields that the waters within the ROZ have decreasing salinities in deeper tests in the ROZ. The lower salinities are proposed to be the result of the long term meteoric derived flushing in the ROZ. As the data suggest that the ROZ and MP originally have similar salinities before MNW and different salinities and Rw's after, it is important to analyze the ROZ waters and determine the correct Rw for the ROZ.

5.2.3.3.3 "Skim" of Oil

In many DST's small quantities of oil will be produced. Because the ROZ oil saturation is at residual to waterflood and the reservoir can be oil wet, it would be expected that there might be small quantities of oil made on a DST. However, a better representation of the predictability of the interval would be obtained by using results from the sample chamber as a measure of the true potential to produce oil, as the sample chamber sample represents the best example of oil, gas, and water production from the reservoir.

5.2.3.3.4 Good To Excelent Pressure

Because there are thinner cycles with more heterogeneity in permeability in the MP, and in the non-productive “tite” interval above the ROZ in Greenfields, there is minimal pressure reduction in the ROZ. The pressure determined for a Greenfield ROZ would be expected to represent the regional pressure of the reservoir, provided there is/has been no production from the interval in the immediate vicinity. Pressures recorded in DST’s of the Brownfield ROZ in producing fields should also have near expected reservoir pressures. In most producing fields that have had long production histories from the MP, but no withdrawal from the ROZ, the ROZ should have essentially virgin reservoir pressures. There may be some drawdown of pressure, although this is probably confined to the uppermost portion of the ROZ where historic completions have frac’ed down into the ROZ interval.

5.2.3.4 Logging

5.2.3.4.1 Water Resistivity (Rw) Different than Main Pay

Traditionally the method historically used to determining the Rw in a producing field, in a potential new field, or new pay discovery, was to use the produced water chemistry, typically from a DST, of the interval below the O/W contact. This assumes, however, that the ROZ Rw is the same as the Rw for the connate water in the pay zone. Considering the water chemistry in the ROZ will have changed as a result of the meteoric derived sweep, and that the meteoric derived sweep has no impact on the water chemistry in the MP, the ROZ Rw will be different than in the MP.

Another assumption historically made was to assume that an Rw for a pay zone could be “back-calculated” using the resistivities at a depth below the “Pay” where the workers assumed that the zone was 100% wet. Back-calculating the Rw for the Pay using this method to determine the Sw for the pay will be in error, if there is a thick ROZ. The Rw derived from that ROZ will generate a misleading Sw for the Pay as there is/was different salinities in the Pay and the ROZ and the presence of sulfur may invalidate the use of a simple Archie’s equation calculation.

5.2.3.4.2 Oil Saturations Varying Greatly from +/- 30%

Oil Saturations (Sw) derived from core in ROZ's tend to be similar to the saturations found as Residual to Waterflood in large, well swept waterfloods. However, a number of operators have reported that attempts to calculate Sw from logs in both Greenfield and Brownfield ROZ's can result in highly variable SW's that do not match the So from the core. One operator reported that 3 different petrophysicists calculated 3 different Sw's for the same wells. There is a suspicion that this is a function of the presence of sulfur rich waters, native sulfur, and variable M and N values input into Archie's Equation. One operator, anecdotally, has reported variations in both saturations and water chemistry during the development of a San Andres CO2 ROZ flood on the eastern side of the Central Basin Platform. To date, there is no solution to this problem.

One other possible explanation is the presence of spotty high oil saturation in the tighter portions of ROZ's. Spotty high oil saturations have been seen in core where, instead of a uniform reduction of saturation occurring in the interval, there are dual porosity/permeability systems and the oil has not been uniformly swept from the interval. This could lead to erroneous high saturation calculations for the entire interval. Further evaluation is necessary.

5.2.3.4.3 Different M and N Values than Main Payzone (MPZ)

As mentioned above, (Archie formula) calculations of Sw's for ROZ's tend to lead to erroneous values. It is not known at this time why this is the case but it is reported that different operators utilize different values for M (cementation factor {varies around 2}) and N (Saturation exponent (generally = 2}) then utilized in the main payzones and that this may lead to the erroneous Sw's derived by petrophysicists.

5.2.3.4.4 Excellent Porosity in Dolomite in ROZs

The ROZ tend to be in the deeper, more open marine portions of the section in the San Andres, the intervals tend to have thicker, more porous cycles, cycle sets and flow units when compared to the thinner more heterogeneous, and less porous cycles and thinner flow units in the Main Payzones (MPZs). The MPZs also tend to have more tidal flat facies which result in lower average porosities on logs, and permeabilities and porosities in core. The ROZ's, similar to the MPZs have been dolomitized. The ROZs however, have undergone a secondary dolomitization associated with the meteoric derived flushing that the MPZs have not undergone. The thicker, more open marine packages, coupled with the flushing related secondary porosity development results in better quality reservoir in the ROZ relative to the MPZ in almost every case.

5.2.3.4.5 “Looks Like a Winner”

There is considerable anecdotal reporting of drilling, mudlog and electric log data together confirming that a Greenfield well is a” winner” and should be cased and successfully completed as a producer. As has been pointed out above, a combination of factors can lead to the erroneous conclusion that a Greenfield, or Brownfield ROZ will be a new field or new pool discovery. Careful evaluation is need to determine the potential producability of a well that has been swept by Mother Nature’s Waterflood using the parameters discussed above. An example of this is the Anschutz #1 Keating well in Gains County.

The Mudlog shown if Figure 5.6, is from the Anschutz #1 Keating in Gaines County. The well was cored from 5454-5503 and 5550 – 5601’ and the presence of a Greenfield ROZ documented in the cored intervals. Between the cored ROZ intervals, the well was drilled and from 5500 – 5550 the samples contained 30 – 60% bright gold fluorescence, and good to excellent porosity. Sample show on the mud log were apparent to a depth of 5750‘. The Neutron Density and Resistivity logs were run and the calculations of oil saturation pointed to casing and completing the well. The well was perfed acidized and tested over a 3 month period. The recovery was 8 BO and +/-3700 BW before the well was plugged.

20 years later, the Tall Cotton ROZ CO_2 Greenfield project was initiated just over 1 mile to the southeast and has produced oil after just 6 months of CO_2 injection. None of the producing wells in the Tall Cotton project would have been primary producers either.

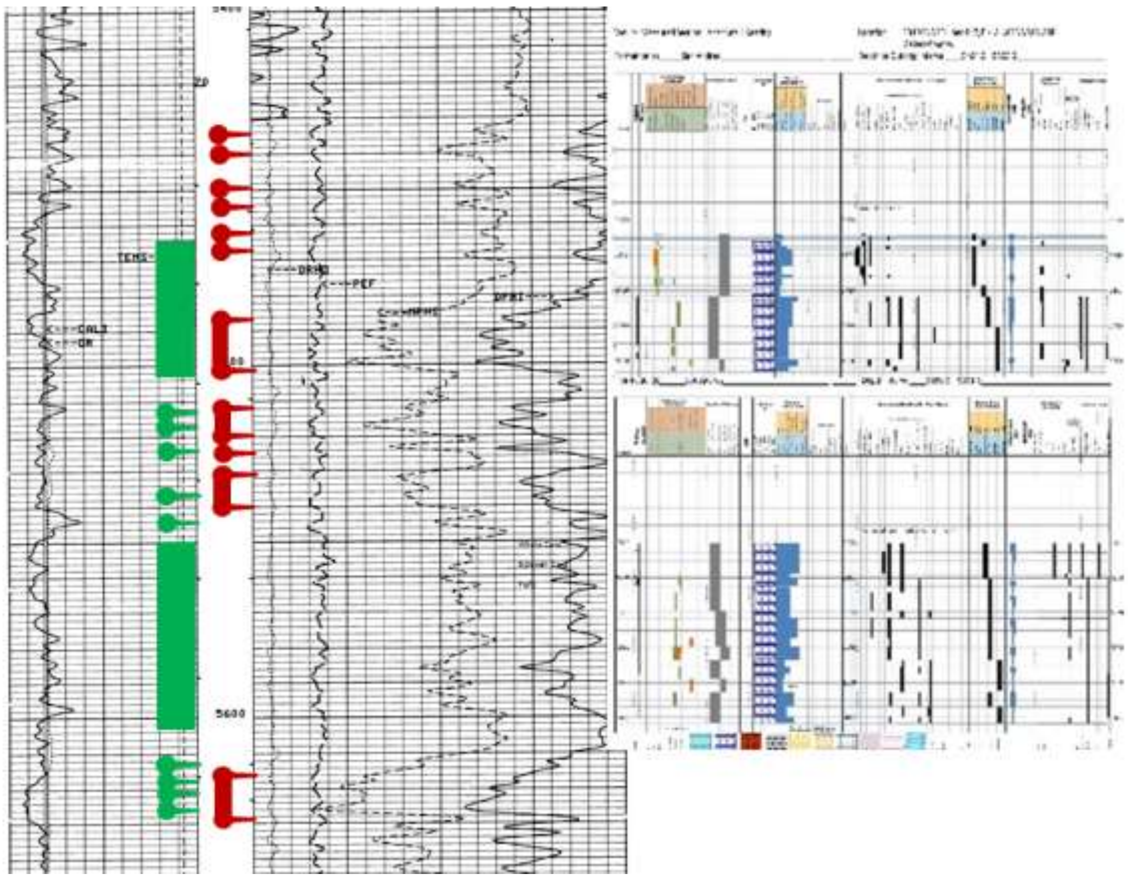


Figure 5.6. Well log and core description for the Anschutz #1 Keating, Gaines County, TX. The GREEN intervals are recovered core, both whole core (solid bar) and sidewall (spikes), and the perfed intervals are shown in RED. The perfs above the cored ROZ intervals tested the shallow subtidal to intertidal “cap” on the open marine ROZ.

5.2.3.5 CORE ANALYSIS

5.2.3.5.1 Five To Forty Percent Oil Saturation

During the study of a CO2 EOR project in the ROZ in the Goldsmith Landreth San Andres Unit (GLSAU), 9 cores, sampling both the MP and the ROZ, were recovered. Standard core analyses were conducted and the So of the MP and ROZ compared. As the Goldsmith Field was an older field with a 40+ yearlong waterflood history, the MP saturations (So) had been reduced to “residual to waterflood”. When compared to the So for the MP, the So for the ROZ’s were almost identical, ranging from 25% to 45%, Figure 5.7. As the ROZ had never been waterflooded by production engineers, we can state that “Mother Nature’s Waterflood” resulted in a sweep efficiency similar to that found in a highly successful modern waterflood.

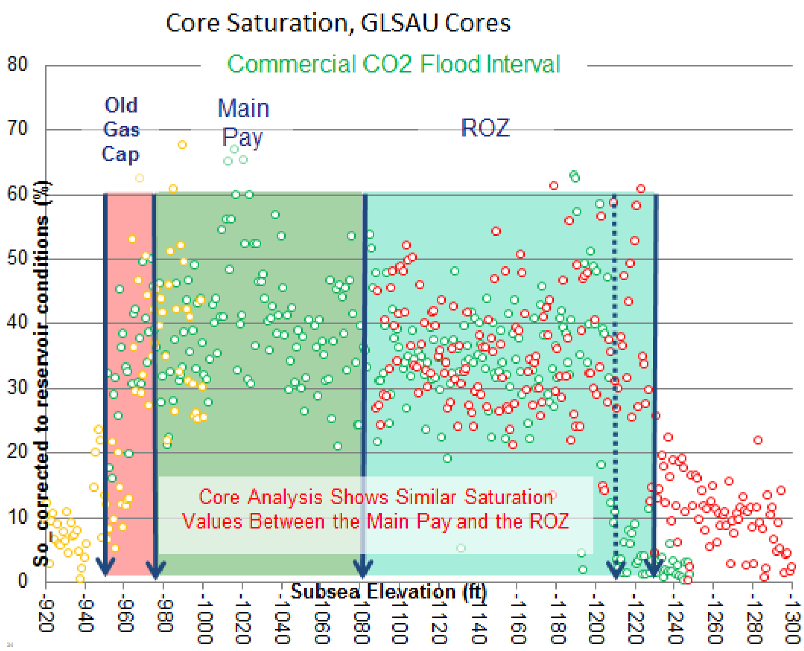


Figure 5.7. Plot of core oil saturation data for a number of wells in the Goldsmith Landreth San Andres Unit (GLSAU) plotted vs. depth. Note the close relationship between the MP "residual to waterflood" (25 – 50%) saturations and the residual to Mother Nature's Waterflood saturations in the ROZ, also 25 - 50%.

5.2.3.5.2 Oil Wet Core

There has been an evolution over time concerning the wetting agent in large carbonate reservoirs in the Permian Basin. During the early decades of development in the basin, it was assumed that all reservoirs were water wet. Over time, it was determined that most carbonate reservoirs are at least partially oil wet, and in some cases predominately oil wet. The oil wetting in ROZs is believed to be enhanced in response to the secondary dolomitization during the meteoric derived flushing and the reduction of oil saturation levels to "residual to waterflood". Based on the evaluation of ROZ cores, ROZs in Permian carbonates appear to be mostly oil wet. The evidence from the brownfield ROZ developments tends to support the San Andres ROZs being predominately oil wet.

5.2.3.5.3 Open Marine Facies

The ROZ's tend to be developed in the deeper, more open marine portions of the San Andres, these intervals tends to have thicker, more porous cycles, cycle sets and flow units when compared to the thinner more heterogeneous, and less porous cycles and thinner flow units in the Main Pays. The main pays also tend to have more tidal flat facies which result in lower average porosities on logs, and permeabilities and porosities in core. See discussion in the Regional Geology section above.

5.2.3.5.4 Solid Hydrocarbon Residue (SHR) Near Base and Top of ROZ

Solid Hydrocarbon Residue (SHR) aka ‘bitumen’ or ‘tar’ is typically found at the traditional oil/water contact (OWC) in fields and at multiple points in fields where there are multiple oil/water contacts. These would not be expected to be found in the interval below the OWC contact if an ROZ were not present. Therefore, the SHR would be found at the paleo OWC contact in either a Greenfield or a Brownfield and at intervals within the paleo-oil column if multiple paleo OWC contacts were present.

5.2.3.5.5 Better Porosity and Permeability Than MPZ

The ROZ’s, similar to the MPZs, have been dolomitized. The ROZ’s however, have undergone a late-stage, secondary dolomitization associated with the meteoric derived flushing that the MPZs have not undergone. The thicker, more open marine packages, coupled with the flushing related secondary porosity results in better quality reservoir in the ROZ. (see Open Marine discussion above).

5.2.3.5.6 “Free” Sulfur Crystals

As discussed above, free sulfur crystals are typically seen only associated with the ROZ. The crystals can range from doubly terminated crystals to botryoidal to void filling masses. Because of the bio-geochemical reactions that take place in the ROZ during the meteoric derived sweep, free sulfur can be found in leached fossils, fractures, vugs and interparticle porosity. As discussed above, the Redox Based Biogenic Reaction is:

$$CaSO_4 + HC \Rightarrow CaCO_3 + H_2O + H_2S$$

5.2.3.5.7 The H_2S is Often Oxidized Back to Elemental Sulfur (S^0).

The sulfur crystals are typically found within the ROZ but also are present in the water zone/paleo oil/water contact immediately below the ROZ and in the lower MP and tight cap above a greenfield ROZ. Some workers have reposted using the presence of native sulfur as an indication that they have reached the oil/water contact in major fields.

5.2.3.5.8 Sulfur and Anhydrite

As discussed above, sulfur crystals are typically seen associated with anhydrite in the ROZ. The sulfur and anhydrite crystals can range from terminated crystals to botryoidal and void filling masses. Because of the bio-geochemical reactions that take place in the ROZ during the meteoric derived sweep, sulfur and anhydrite can be found in fractures and vugs. Sulfur and anhydrite associations are typical of void filling minerals.

5.2.3.5.9 Sulfur and Calcite

As discussed above, sulfur crystals are typically seen associated with calcite in the ROZ. The sulfur and calcite crystals can range from terminated crystals to botryoidal and void filling masses. Because of the bio-geochemical reactions that take place in the ROZ during the meteoric derived sweep, sulfur and calcite can be found in fractures and vugs. Sulfur and calcite associations are typical of void filling minerals.

5.2.3.5.10 Spotty Oil Stain

The presence of spotty high oil saturation in the tighter portions of ROZ's has been noted in core, Figure 5.8. Spotty high oil saturations have been seen in core where, instead of a uniform reduction of saturation occurring in the interval, there are dual porosity/permeability systems (large burrows for example) and the oil has not been uniformly swept from the interval.

Figure 5.8. Spotty oil stain in tighter portion of burrowed open marine wackestone, Chevron H. S. A. #1548, Ward County, TX. Near base of ROZ.

This could lead to erroneous high saturation, especially if plug analyses are performed and the plug is recovered from the higher oil saturated interval. The higher oil stain is likely to be found in the porosity/permeability fraction where there is lower permeability and the reservoir was therefore isolated from the meteoric derived sweep. Whereas the higher permeability portion was swept to residual to waterflood. Log calculations would average the two saturations and render a higher So than in other portions of the ROZ.

5.2.3.5.11 Leached Moldic Porosity

Below the ROZ, coincident with the transition from dolomite above to limestone below, the open marine fossils, such as fusulinids, will be complete, with preserved internal structures in the limestone, however, in the dolomitic ROZ, the fossil grains will be leached partially or completely. In some cases it is apparent that the grains were leached –then filled partially, or completely, with anhydrite- then the fusulinid mold partially or completely leached again. There is often a “dolo-trash” of small crystals found at the bottom of the leached fusulinids indicating that the mold have had multiple periods of filling and leaching. This is related to the meteoric derived flushing.

5.2.3.5.12 Leached Fractures

There are examples of leached fractures in the ROZ where there is no crystal growth or oil stain/SHR on the fracture faces, Figure 5.9. This suggests that the fractures have been leached POST Mother Nature’s Waterflood. This suggests that they are related to the continuing meteoric derived flow that maintains the tilted oil/water contacts in the present day oil column.

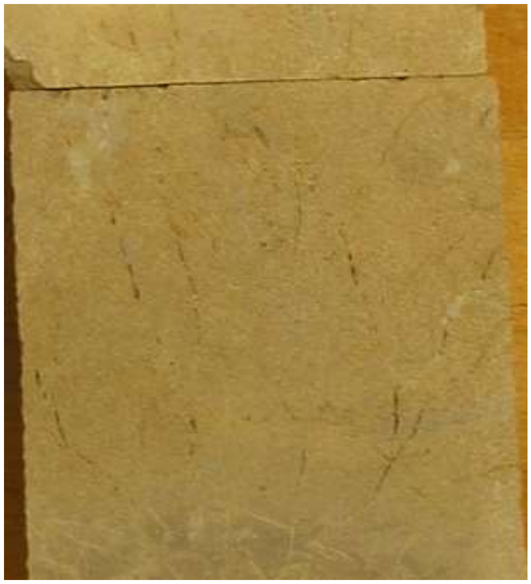


Figure 5.9. Leached fractures in core. The fractures are post oil emplacement as the faces of the fractures are "clean" with no oil stain.

5.2.3.5.13 Fabric Destructive Dolomitization

The transition between Fabric Destructive Dolomite in the ROZ and the Fabric Selective Dolomite in the partially dolomitized “limestone” below the ROZ has been shown to occur within a foot in the core, Figure 5.10. In the GLSAU in the Goldsmith field, the interval below the transition matrix is a mix of the original lime mud, and euhedral dolomite grains. Above the transition, the dolomite is almost all fabric destructive, with mostly subhedral to anhedral crystals with only a few relic euhedral crystals, and little if any calcite. This is good evidence that the fabric destructive dolomitization is associated with the meteoric derived flushing event, and not associated with the early dolomitization event that resulted in the deposition of the euhedral crystals seen below.

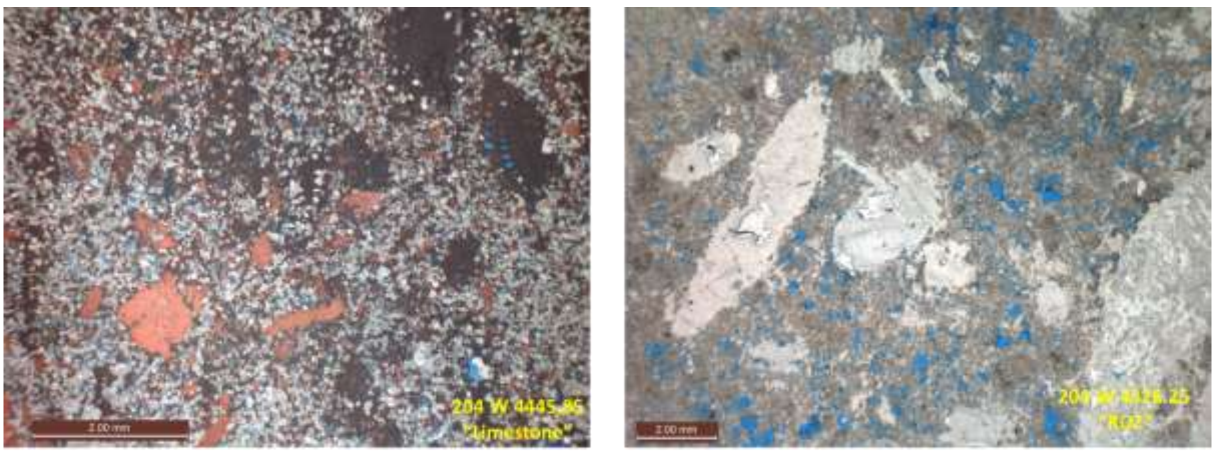


Figure 5.10. Comparison of (A) Limestone below ROZ with small euhedral dolomite crystals (white crystals) fusulinids with preserved internal structure, and patchy calcite (pink) cement, #204 W GLSAU, depth 4445.85, with (B) subhedral to anhedral dolomite with fusulinids replaced with anhydrite from ROZ, depth 4326.25.

5.2.3.5.14 Limestone Below the Base of the ROZ

The “Limestone” below the transition contains complete calcitic or aragonitic fossils, often fusulinids with complex internal structures, and other fossil grains. The matrix is a mix of the original lime mud, and euhedral dolomite grains. These small dolomite crystals are most often doubly terminated and appear to have been non-displacive grains. These grains are believed to be associated with the early dolomitization event of the open marine section of the reservoir.

The limestone below the transition is typically recorded on the porosity logs are partial dolomite (separation is seen on the neutron-density plot, but not the amount of separation seen when the rock is 100% dolomite). The PE curve also records a value that falls between the 3.13 of dolomite and 5.09 of limestone.

5.2.3.6 Completion

5.2.3.6.1 Large Volumes of Fluid (Sulfur Water)

ROZ wells are capable of producing large volumes of water during DST or upon completion. Examples of this are some of the Tubb Carbonate wells in the North Ward Estes area where large volumes of water were reported on IP's, Table 2. Although Sulfur water or salty sulfur water are not reported as such on

H. S. A.	1561	IPP 10 BO, 126 MCF, 4591 BW
H. S. A.	1564	IPP 9 BO, 10 MCF, 3133 BW
H. S. A.	876	IPP 13 BO, 88 MCF, 2185 BW
H. S. A.	1164	IPP 25 BO, 24 MCF, 4165 BW

Table 5.2. IP's for selected Tubb Carbonate completions, North Ward Estes area.

completion reports, many of the Drill Stem Tests (DSTs) of the interval reported salty sulfur water or sulfur water: Gulf #319 G' W. O'Brien DST TUBB 5850-5911 rec 210' of gas cut mud (GCM) & 360' salty sulfur water, is an example. The large volumes of fluid being produced is indicative of the potential for flushing associate with Mother Nature's Waterflooding.

5.2.3.6.2 Less Than 5% Oil Cut During Completions

Wells identified to have been completed in intervals that have been swept or partially swept (ROZ), but have higher oil saturations than residual to waterflood will produce some oil upon completion. However, the oil cut will typically be low. There are a number of examples with oil cuts in the 5 to 25% range in the "near" ROZ's (at the top of the ROZ often referred to as the Transition Zone, or TZ). These wells also typically make large total fluid volumes, and are probably testing oil wet intervals (TZ's?) and will, over time, see continued increases in water cut until the well is abandoned. The exception to this are wells where the pressures are being significantly reduced, there is gas breakout, and a corresponding increase in oil production.

5.2.3.6.3 Good to Excelent Pressure

Because there are thinner cycles with more heterogeneity in permeability in the MP, and in the non-productive “tite” interval above the ROZ in Greenfields, there is minimal pre-production pressure reduction in the ROZ. The pressure determined for a Greenfield ROZ would be expected to represent the regional pressure of the reservoir, provided there is/has been no production from the interval in the immediate vicinity. Pressures recorded in DST’s of the ROZ associated with MP’s in producing fields should also have near expected reservoir pressures. In most producing fields that have had long production histories from the MP, but no withdrawal from the ROZ, the ROZ should have essentially virgin reservoir pressures. There may be some drawdown of pressure, but this is probably confined to the uppermost portion of the ROZ.

5.2.3.6.4 Lower Salinity than Expected

San Andres salinities can vary from the Central Basin Platform (CBP) to the Northwest Shelf (NWS), and from area to area on the CBP and NWS. However there is a growing body of evidence that salinities can be considerably different from the MP to the ROZ in a Brownfield, and even vary vertically within a single Greenfield or Brownfield. As discussed in the Rw section above, considering the water chemistry in the ROZ will have changed as a result of the meteoric derived sweep, and that the meteoric derived sweep has no impact on the MP water chemistry, the salinities in an ROZ will be different than that of the MP and can differ within the ROZ, often being significantly fresher with increasing depth.

5.2.3.6.5 Different Scale Deposits than MPZ

San Andres water chemistries and salinities in the MP and the ROZ can be considerably different in a Brownfield example, and even vary vertically within a single Greenfield or Brownfield. As the water chemistry can vary significantly, with different sulfur (SO4) content being the primary change, it stands to reason that the scale will differ as well. In many fields, the flood patterns for the ROZ’s differ from the flood patterns in the MP, with different, or comingled producing wells for each interval. In almost every instance the scale in the producing ROZ interval, and therefore the near wellbore, is different than the scale in the wells producing from the MP only. Careful attention must be paid to the scale treatment in the ROZ. There is evidence from an number of CO2 flooded fields where inattention to scale issues have severely restricted production, and only when an ROZ-specific scale program was introduced did the wells reach optimum production. Water Alternation Gas (WAG) flood waters utilized in the MP, have had, in most cases, decades to equilibrate with the connate waters in the MP. However, as the waters produced from, and injected into the ROZ will be different than both the connate waters and the flood waters in the MP, scale treatments in the ROZ will need to be carefully crafted for a totally different produced water.

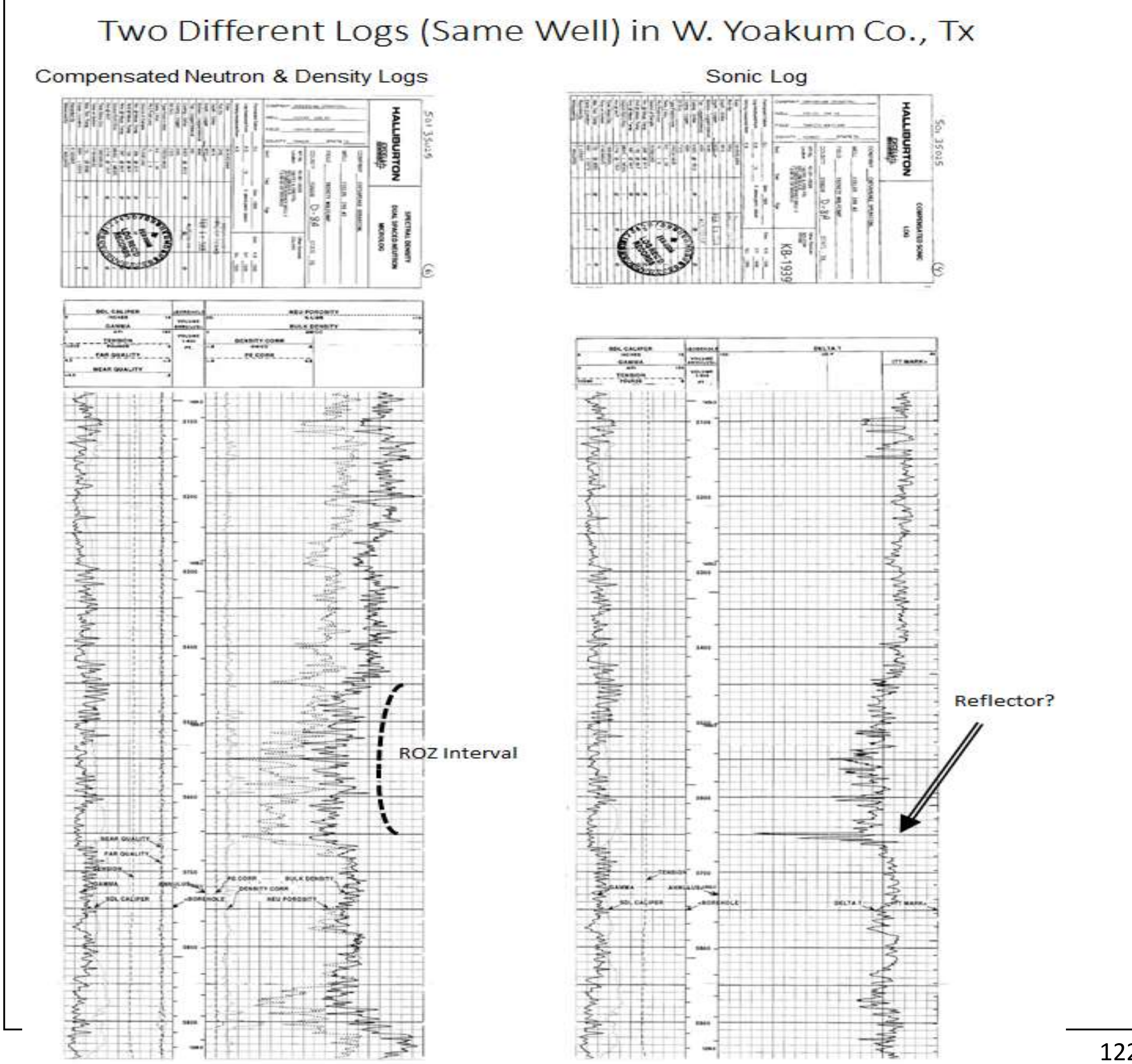
Chapter 6 - GEOPHYSICAL STUDIES

(Authors: Melzer and Andrew D. Bell, Consulting Geophysicist, Midland, Texas)

6.1 GEOPHYSICAL STUDY BACKGROUND

As discussed in the previous chapter, many times in the San Andres formation, the ROZ is "perched" above a tight, marine dolomite we often refer to as a wackestone. This is not a reservoir rock owed to its low permeability and porosity and possesses a slightly higher sonic velocity that the overlying ROZ interval. If the impedance mismatch between the base of the ROZ and the underlying wackestone (as shown in Figure 6.1) could be identified on high quality

Figure 6.1 – Example Well Showing a Sharp "Bottom" to the ROZ Interval



seismic reflection data, then the base of the ROZ could be mapped in three-dimensions between the well control and wireline data points nearby. With this in mind, the project personnel approach Mr. Bell with the idea of identifying both an area to look for the ROZ base mapping but also to utilize his skills to review the data prior to absorbing the costs of either or both the purchase of a section of the geophysical survey and the reprocessing of the data.

In the effort to determine an appropriate area for the project, the project team identified several rich ROZ areas with sufficient well control documenting geological concepts and petrophysical analyses. The Gaines County region was of particular interest as it possessed a good sampling of wireline logs including the needed sonic log data control. The area also lies at the center of several ROZ development projects. The areas of interest were then prioritized by the extent of seismic coverage of appropriate vintage/parameters for detailed investigation/analyses and probability of significant data quality improvement from highly focused reprocessing. The top prioritized area was covered by a particular geophysical company's regional survey (speculative "shoot") and the team refined their interest to an area of ~57 square miles. Despite some limitations (1994-vintage 6-line patch, nominal 21-fold, etc.), the team was encouraged by Mr. Bell when he was able to view the raw data and witnessed a favorable data quality and consistent data acquisition (minimal skips) sufficient for reprocessing for the needed analyses.

6.2 PROPOSAL

The geophysical company was approached to provide the data at no cost and the project would pay for all reprocessing. The reprocessing focus was to be on the San Andres to Tubb interval (including the Glorieta andClearfork section). The analysis was to be conducted by Mr. Bell with the project team involvement and results would be made available to the company. The project team would provide the well control and velocity calibration (synthetics generated from sonics over the interval of interest with geological/geophysical input from Mr. Bell and Dr. Trentham (UTPB).

The Company would initiate the reprocessing of the survey data over the area of interest in coordination with the project geophysicist, with particular emphasis on attaining superior high-resolution (vertical) and various attribute analyses including anisotropic analyses and heterogeneity, at a cost of $25,000. The reprocessed data over the area of interest was to be provided to the project geophysicist only for his analyses and interpretation

Any exhibits that would be created from the data to illustrate the project results were recognized to have been pre-authorized by the Company with an expectation that the precise location of the sourced data would be properly ‘cropped-out’ and exhibits allowed with proper acknowledgements in its presentations/reports, as well as a summary of the data acquisition and reprocessing. The geophysical project’s results were to have been included here in the final project report.

After considerable deliberation and negotiations, it was determined that the geophysical company would not allow the project to proceed for the budgeted funds. Conducting a limited area survey within the project was not economically feasible. Alternative companies and sources of geophysical data were not available in the desired area of interest so the task had to be abandoned.

Chapter 7 - ESTIMATING THE PERMIAN BASIN SAN ANDRES ROZ RESOURCE

7.1 INTRODUCTION

Author: L.S. Melzer

Shortly after publication of Ref 7.1, not only were the origins of the ROZs in the Permian Basin San Andres formation more widely recognized but they were understood to extend to considerable depths below existing fields. CO_2 EOR exploitation of a few of those fields and their ROZs were already underway, e.g., Wasson and Seminole, so an effort was initiated by Advanced Resources International to utilize their data base and knowledge of other anchor San Andres fields and characterize and quantify the extent of the ROZ resource beneath those fields. The reader is directed to the full report (Ref 7.2) but the results of this “brownfield” ROZ resource assessment is briefly summarized in Section 7.2 that follows.

The magnitude of the brownfield ROZ resources is impressive in terms of oil in place resources but it was felt that the residual oil resources would be even greater owed to the large of expanse of the paleo San Andres oil field that had been swept between the modern-day fields. Those resources were dubbed greenfield resources since, if they were to be exploited, new wells would be required in contrast to the deepening of wells in the exiting producing fields.

This report provides the original reporting of the ARI study of those greenfield oil-in-place (OIP) resources for a twelve-county study area in the Permian Basin. The twelve counties were chosen to contain the scope of the study to a manageable level but were envisioned to represent the majority of the expected resource on the basis of the current understanding of the ROZ fairways (see Fig 3.2). Admittedly, some bias was naturally applied to areas where successful CO_2 floods were underway. These 12 counties possessed 85% of the San Andres formation CO_2 floods and 75% of the San Andres EOR oil production according to the reference Oil and Gas Journal Survey in 2010 (Ref 7.3).

One will note that we use the term OIP for the ROZ oil in contrast to the more commonly used term original oil-in-place (OOIP). This is done to avoid confusing the ROZ oil resources with those “original” resources of oil that were present in the paleo trap and prior to the natural water flood sweep during the early Tertiary time frame. This terminology is important for another reason as well; the normalization methods for comparing recovery efficiency utilizing OOIP and/or original hydrocarbon pore volume (HCPV). If the ROZs have been water flooded by ‘mother nature’, the baselines for normalization purposes are different and necessitates a reconstruction of ROZ OIP back to an OOIP prior to the natural water flood. To cite an example of this – if a modern day CO_2 flood of a main pay zone can produce, say, 15% of the OOIP, an equally efficient CO_2 flood of the OIP in a ROZ, with its previously water flooded, modern-day OIP, might produce upwards of 25% to 40% of the OIP in a ROZ. But to be able to compare the efficiencies of CO_2 floods of a MPZ to one of a ROZ, the OIP of the ROZ will need to be projected back to the OOIP prior to the natural water flood sweep.

The last section of this Chapter (7.4) addresses the technically recoverable ROZ resource in four of the 12-counties. Time precluded conducting these studies for all of the 12-counties so the work was concentrated on Gaines, Yoakum, Terry and Dawson counties, The hope is that the work there will be somewhat proportionately representative of the other eight counties.

7.2 Brownfield Resource Assessment

Authors: Advanced Resources International

A significant portion of the ROZ resource potential exists beneath many of the major San Andres oil fields in the Permian Basin “brownfields”. Reference 7.1.2 provides a limited look into documenting the in-place and recoverable ROZ potential beneath existing oil fields in this important domestic oil production basin. This initial work cited in Reference 7.1.2 was conducted in 2006. Given the gains in understanding about the nature of the ROZ, a more in-depth and updated review, comparable to the work performed on the San Andres ROZ “fairway” of the Permian Basin, is needed to bring this resource assessment up to date. Still, these results provide insight into the in-place and potential recoverability of this important resource. Additionally, some fields beyond the San Andres formation were included in this review.

7.2.1 Overview of Brownfield ROZ Recovery Potential

Because of their low to moderate residual (“close to immobile”) oil saturation conditions, ROZ resources are not economic to produce using primary or secondary oil recovery methods. As such, domestic oil wells have traditionally been completed in the Main Pay Zone (MPZ), at or above the oil-water contact (the first observance of significant mobile water). As a result, the wells were consistently completed above the ROZ. Outside of a small group of forward looking operators, little is still known about the ability to successfully identify and produce the ROZ resource. However, in the current economic climate, with operators’ desires to extend reservoir life, ROZ resources offer an important new source of domestic oil production. Because of this, there is growing interest in further understanding the resource size and recoverable oil potential in the relatively thick (100 to 300 feet) ROZs located beneath the MPZs of oil reservoirs. The oil saturations in the ROZs of a reservoir are often similar to the oil saturations left after water flooding. As such, with progress in CO_2 flooding technology and availability of affordable supplies of CO_2, the oil resource in the ROZ could more readily become an economically viable target.

Further confirmation of this new oil resource potential is provided by the various ROZ CO_2 EOR pilot tests currently underway. Several of these pilot tests are operated by Oxy Permian in the Wasson field. Of these, the Denver Unit (DU) pilot was the first to target the residual oil zone. An equally important trial was implemented in the Seminole San Andres Unit (SSAU) in 1996, is operated by Hess Corporation. This was a 500-acre pilot ROZ CO_2 flood that continues to operate today. The response from this field pilot test was very promising, providing an estimated cumulative recovery comparable to a similarly sized flood in the MPZ and a peak oil rate of 1,400 bbls/day. The Denver Unit and SSAU pilots proved the commerciality of the ROZ Decisions have been made by both operators since the publication of this report in 2006 to expand the early pilots into field-wide projects exploiting these brownfield ROZs.

7.2.3 Methodology Used for the Brownfield ROZ Recovery Potential

The CO_2-PROPHET steamtube model was utilized for the resource assessment. As part of the assessment, the model was calibrated with a full-scale, industry standard compositional reservoir simulator. The CO_2-PROPHET tool provided an excellent match of oil recovery, for both the MPZ floods and the ROZ CO_2-EOR projects for a sampling of major Permian Basin oil fields. As a result, there was confidence in using the CO_2-PROPHET model to estimate oil recovery from the ROZ for the remaining Permian Basin oil fields assessed by the 2006 study.

7.2.4 Fields Examined

A total of 55 oil fields were examined to assess the quality of the in-place and technically recoverable ROZ resource beneath these fields. This set of fields is divided into five regions and are shown in the following Tables (7.2.1-7.2.5). These tables exhibit the oil field, its location (RR district), and the fields cumulative MPZ oil production, as of the beginning of 2003.

Table 7.2.1 – Large Northern Shelf Carbonate (San Andres) Oil Reservoirs with Potential for ROZ Resources

Field	RR District	Cumulative Oil Production (MMB)(1-1-03)
1. Adair	8A	68.1
2. Brahaney	8A	56.0
3. Cedar Lake	8A	110.0
4. Levelland Unit	8A	662.0
5. Ownby	8A	18.9
6. Prentice 6,700	8A	154.2
7. Prentice	8A	48.7
8. Reeves	8A	34.6
9. Slaughter	8A	1,234.7
10. Wasson	8A	1,883.9
11. Wasson 72/66	8A	107.4
12. Welch	8A	173.0

Table 7.2.2 – Large North Central Basin Platform (San Andres/ Grayburg) Oil Reservoirs with Potential for ROZ Resources

Field	RR District	Cumulative Oil Production (1-1-03)
1. Emma	8	47.0
2. Fuhrman-Masco	8	119.2
3. Means	8	240.6
4. Seminole	8A	620.5
5. Seminole, W	8A	48.0
6. Shafter Lake	8	50.8

Table 7.2.3 – Large South Central Basin Platform (San Andres/Grayburg) Oil Reservoirs with Potential for ROZ Resources

Field	RR District	Cumulative Oil Production (1-1-03)
1. Cowden, N.	8	553.8
2. Cowden, S.	8	163.0
3. Dune	8	193.0
4. Foster	8	289.0
5. Goldsmith, N.	8	21.2
6. Goldsmith	8	359.2
7. Harper	8	50.8
8. Johnson	8	36.7
9. Jordan	8	91.5
10. Lawson	8	16.2
11. Mabee	8	118.4
12. McElroy	8	561.6
13. Midland Farms	8	163.3
14. Penwell	8	102.0
15. Sand Hills McKnight	8	129.6
16. Wadell	8	110.0

Table 7.2.4 – Large Horseshoe Atoll (Canyon) Oil Reservoirs with Potential ROZ Resources

Field	RR District	Cumulative Oil Production (1-1-03)
1. Adair	8A	52.5
2. Cogdell	8A	265.8
3. Diamond M	8A	251.3
4. Kelly-Snyder	8A	1,264.9
5. Reinecke	8A	86.3
6. Salt Creek	8A	367.8
7. Von Roeder (+NVR)	8A	367.8
8. Wellman	8A	74.6
9. Oceanic	8	24.3
10. Vealmoor E.	8	63.0

Table 7.2.5 – Large Eastern New Mexico (San Andres) Oil Reservoirs with Projected ROZ Resources

Field	RR District	Cumulative Oil Production (1-1-03)
1. Cato	East NM	16.3
2. Chaveroo	East NM	24.5
3. Flying M	East NM	11.6
4. Hobbs	East NM	342.7
5. Vacuum	East NM	355.9
6. Bluitt	East NM	2.5
7. Sawyer	East NM	1.8
8. Mescalero	East NM	7.1
9. Todd	East NM	2.9
10. Twin Lakes	East NM	5.6
11. West Sawyer	East NM	9.4

Table 7.2.6 summarizes the size of the ROZ OIP resource in five oil plays of the Permian Basin.

Table 7.2.6 – Estimates of the ROZ Oil in Place, Five Permian Basin Oil Plays

Field/Unit	ROZ OIP (BB)	No. of Fields	No. of MPZ Fields with CO2-EOR Projects	No. of Fields with ROZ CO2-EOR Projects
1. Northern Shelf Permian Basin (San Andres)	13.2	12	5	1
2. North Central Basin Platform (San Andres/Grayburg)	2.6	6	2	1
3. South Central Basin Platform (San Andres/Grayburg)	7.9	16	5	0
4. Horseshoe Atoll (Canyon)	2.9	10	4	2
5. East New Mexico (San Andres)	4.1	11	2	0
Total	**30.7**	**55**	**18**	**4**

The 2006 resource assessment work by ARI, recaptured in Table 7.2.6 included the OIP in other formations beyond the San Andres; i.e., the Grayburg and Canyon, with a total OIP "brownfield" ROZ resource of 30.7 billion barrels (B bbls).

A further review of this work suggests that the contribution of the Grayburg formation in the North Central Basin Platform area is very minor (essentially zero), but the Grayburg could represent as much as half the ROZ resource in the South Central Basin Platform area, So, the San Andres ROZ oil resource can be estimated to be the 30.7 B bbls less the Grayburg and Canyon contributions, or 23.8 B bbls within 46 San Andres ROZ brownfields.

The 2006 ARI brownfield assessment report also examined the technically recoverable component of the ROZ OIP resource, Table 7.2.7.

Table 7.2.7– Technical Oil Recovery Totals, Five Permian Basin Oil Plays

Field/Unit	ROZ CO_2-EOR (BB)
1. Northern Shelf Permian Basin (San Andres)	5.5
2. North Central Basin Platform (San Andres/Grayburg)	0.9
3. South Central Basin Platform (San Andres/Grayburg)	2.9
4. Horseshoe Atoll (Canyon)	1.3
5. East New Mexico (San Andres)	1.3
Total	**11.9**

As with the resource assessment, the contributions from the Grayburg and Canyon formations need to be removed to obtain a clean San Andres recovery estimate. Removing half the oil recovery from the South Central Basin Platform (Grayburg contribution) and all of the Horseshoe Atoll (Canyon) reduces the anticipated recovery by 2.8 B bbls. The result is 9.1 B bbls of technically recoverable San Andres "brownfield" ROZ oil, equal to 38% of the estimated San Andres brownfield ROZ oil in place.

Subchapter References

7.1.1 Melzer, L.S. (2006), Stranded Oil in the Residual Oil Zone, Prepared for Advanced Resources International and U.S. Department of Energy's, Office of Fossil Energy - Office of Oil and Natural Gas, Melzer Consulting, February 2006.

7.1.2 Koperna, G. J. and Kuuskraa, V.A. (2006), Technical Oil Recovery Potential from Residual Oil Zones: Permian Basin, Prepared for the U.S. Department of Energy's Office of Fossil Energy - Office of Oil and Natural Gas, Advanced Resources International, February 2006

7.1.3 Oil & Gas Journal Annual Production Report, Apr 19, 2010 Edition

7.3 Four County Executive Summary

Authors: Advanced Resources International

This Permian Basin San Andres ROZ "fairway" assessment report, entitled *"Defining an Overlooked Domestic Oil Resource: Part I. A Four-County Appraisal of the San Andres Residual Oil Zone (ROZ) "Fairway" of the Permian Basin",* addresses a four-county area within the West Texas portion of the Permian Basin - - Gaines, Yoakum, Terry and Dawson counties - - Exhibit 7.3.1 - EX-1.

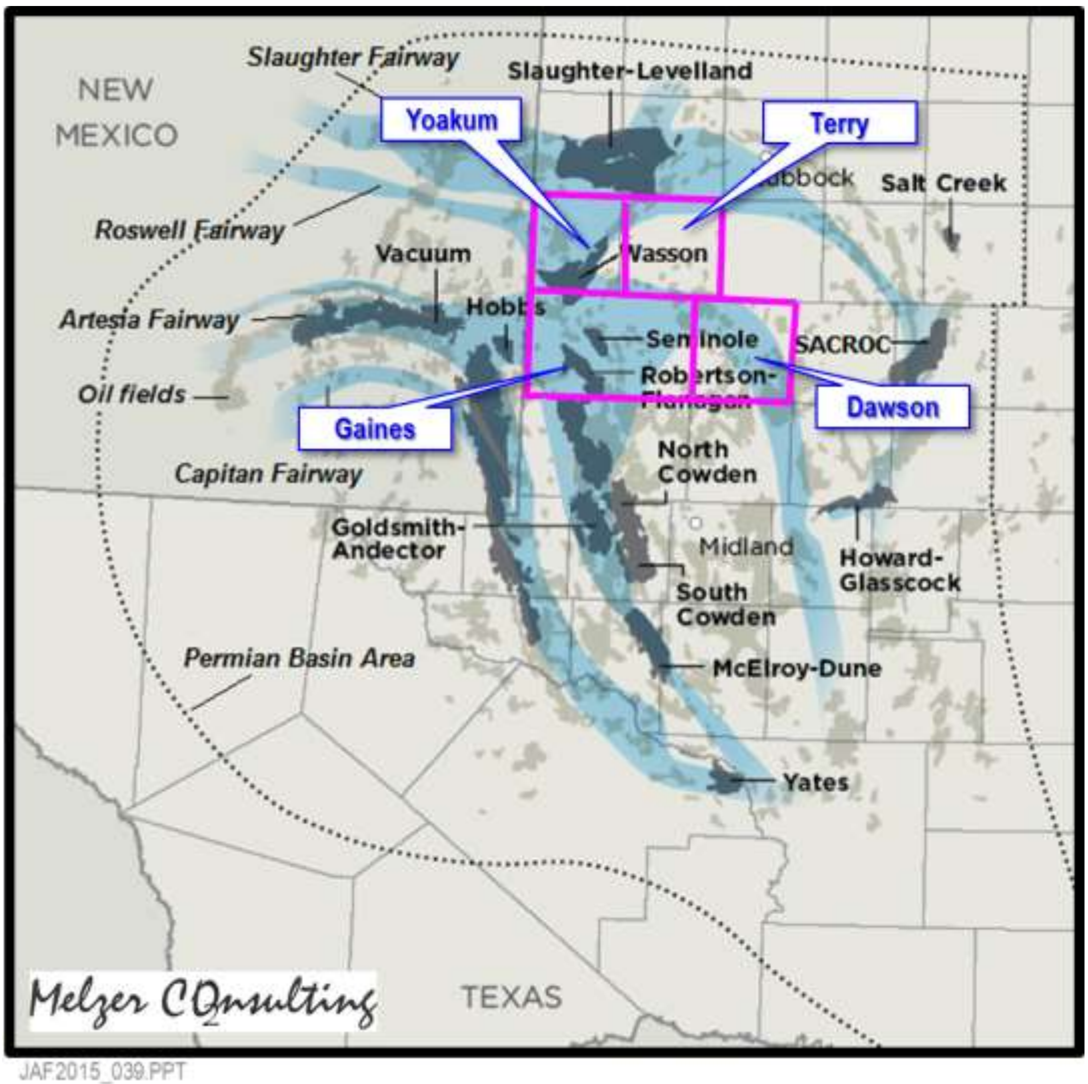


Exhibit 7.3.1 (EX-1) San Andres ROZ "Fairways " of the Permian Basin, West Texas

Source: Melzer Consulting, 2014.

The four-county San Andres ROZ “fairway” resource assessment has been undertaken to address one fundamental question:

1. *What is the size and distribution of the in-place San Andres ROZ “fairway” oil resource available for CO_2-EOR?*

Our assessment of the San Andres ROZ “fairway” resource in Gaines, Yoakum, Terry and Dawson counties of West Texas identifies 111.9 billion barrels of oil in-place. Much of the in-place San Andres ROZ “fairway” resource in this four-county area is “higher quality” (porosity greater than 8% and oil saturation greater than 25%), offering promise for commercially viable development with by-produce storage of CO_2, Exhibit 7.3.2 (EX-2).

Exhibit 7.3.2 (EX-2) In-Place San Andres ROZ "Fairway" Resources: Four-County Area of West Texas

County	In-Place Resources		
	Total (B Bbls)	Higher Quality (B Bbls)	Lower Quality (B Bbls)
Gaines	45.5	35.4	10.1
Yoakum	20.7	16.1	4.6
Terry	17.9	10.6	7.3
Dawson	27.8	14.6	13.2
Total	**111.9**	**76.7**	**35.2**

Source: Advanced Resources International, 2015.

Our study’s assessments of the key volumetric San Andres ROZ “fairway” properties - - gross and net pay, porosity and oil saturation - - are consistent with publically available data. For example, the geologic data reported for Kinder Morgan’s “Tall Cotton” ROZ “fairway” project in western Gaines County and the data reported for the ROZ interval below the main pay zone of the Seminole oil field in central Gaines County are similar to the data derived from our study’s log analysis for Partition #3 of Gaines County, Exhibit 7.3.3 (EX-3).

Exhibit 7.3.3 (EX-3) Comparison of Gaines County Volumetric San Andres ROZ "Fairway" Reservoir Properties: Tall Cotton ROZ "Fairway", Seminole Oil Field ROZ, and This Study's Partition #3

Volumetric Reservoir Properties	Seminole Oil Field ROZ[1, 2]	"Tall Cotton" ROZ "Fairway"[3]	This Study Partition #3		
	(ROZ "1" Only)	(ROZ "1" & ROZ "2")	ROZ "1"	ROZ "2"	Total
Gross Pay (feet)	246	540	244	248	492
Net Pay (feet)	197	450	208	224	432
Porosity (%)	12.8%-15%	12%	10.2%	9.7%	10%
Oil Saturation (%)	32%	35% to 50%	36%	36%	36%

[1]Honarpour, M., 2010. [2]Bush, J., 2001. [3] Railroad Commission of Texas, 2014.
Source: Advanced Resources International, 2015.

This study, entitled *"Defining an Overlooked Domestic Oil Resource: Part I. A Four-County Appraisal of the San Andres Residual Oil Zone (ROZ) "Fairway" of the Permian Basin",* draws on the extensive geological and log analyses performed by Advanced Resources International, in partnership with the University of Texas of the Permian Basin (Dr. Robert Trentham) and Melzer Consulting (Mr. Steve Melzer), sponsored by the Research Partnership to Secure Energy for America (RPSEA).

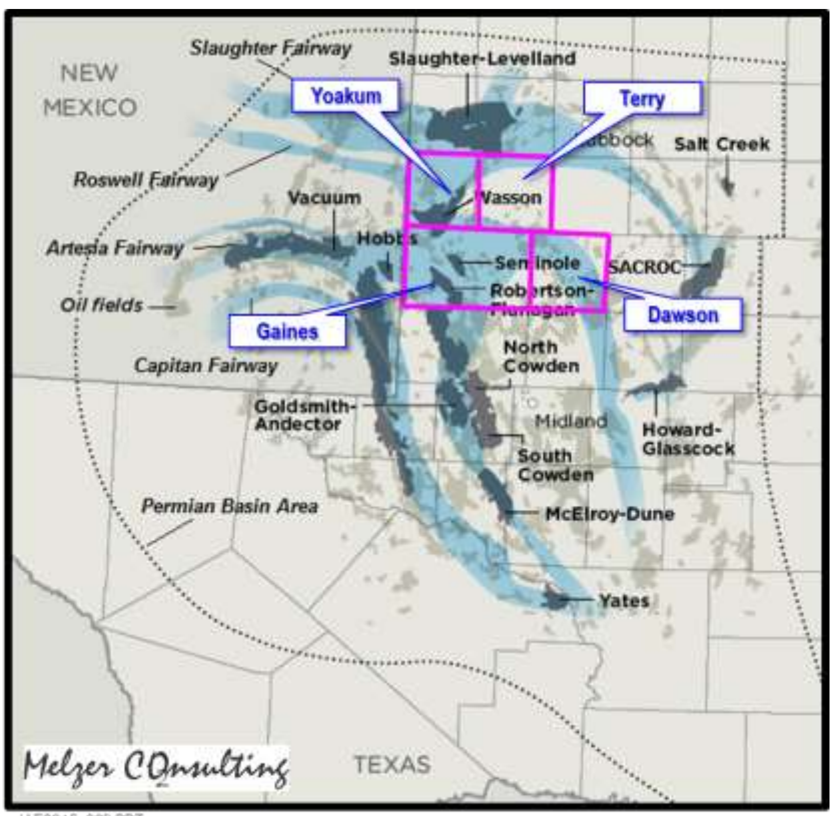
7.3.1 Four County Study - Introduction

Our geological assessment of the San Andres residual oil zone (ROZ) “fairway” resource addresses a four-county area - - Gaines, Yoakum, Terry and Dawson counties - - of the West Texas portion of the Permian Basin. This assessment has one main purpose - - to establish the potential for storing CO_2 in the geological intervals that underlie the ROZ “fairways” in these four counties.

The Four-County Study Area

The San Andres ROZ “fairway” resource assessment addresses a four-county area within the West Texas portion of the Permian Basin - - Gaines, Yoakum, Terry and Dawson counties, as shown on Exhibit 7.3-1. As such, this four-county ROZ assessment incorporates the Slaughter and Roswell ROZ “fairways” on the northern portion of the Permian Basin, where they merge with the Artesia “fairway.” Additional ROZ “fairway” resources surround this four-county area.

Exhibit 7.3-1 San Andres ROZ “Fairways ” of the Permian Basin, West Texas



JAF2015_039.PPT

Source: Melzer Consulting, 2014.

A series of major oil fields - - Wasson, Seminole, and Robertson, among others - - are located within these four counties. The areas underneath the structural closure of these oil fields have been excluded from the San Andres ROZ “fairway” resource assessment. (See previously published report that addresses the San Andres ROZ resource within the structural closure of Permian Basin oil fields. (Advanced Resources International, 2006))

The ROZ resources in the San Andres Formation in the study area represent the bypassed oil in a huge paleo-oil reservoir that was swept by a natural (“nature’s”) waterflood during the Tertiary period. Transmitting information on the size of the remaining oil resource in the San Andres ROZ “fairway”, on its technical and economic recoverability, and on its associated CO_2 storage capacity using miscible CO_2 enhanced oil recovery (CO_2-EOR) is the primary purpose of this report.

The Permian Basin: Geologic Setting

The Permian Basin, located in West Texas and Southeast New Mexico, contains one of the world’s thickest deposits of sediments from the Permian period and encompasses a massive area, 250 miles wide (east to west) and 300 miles long (north to south). The paleogeography of the Permian Basin developed as the result of basement deformation during the preceding Pennsylvanian period.

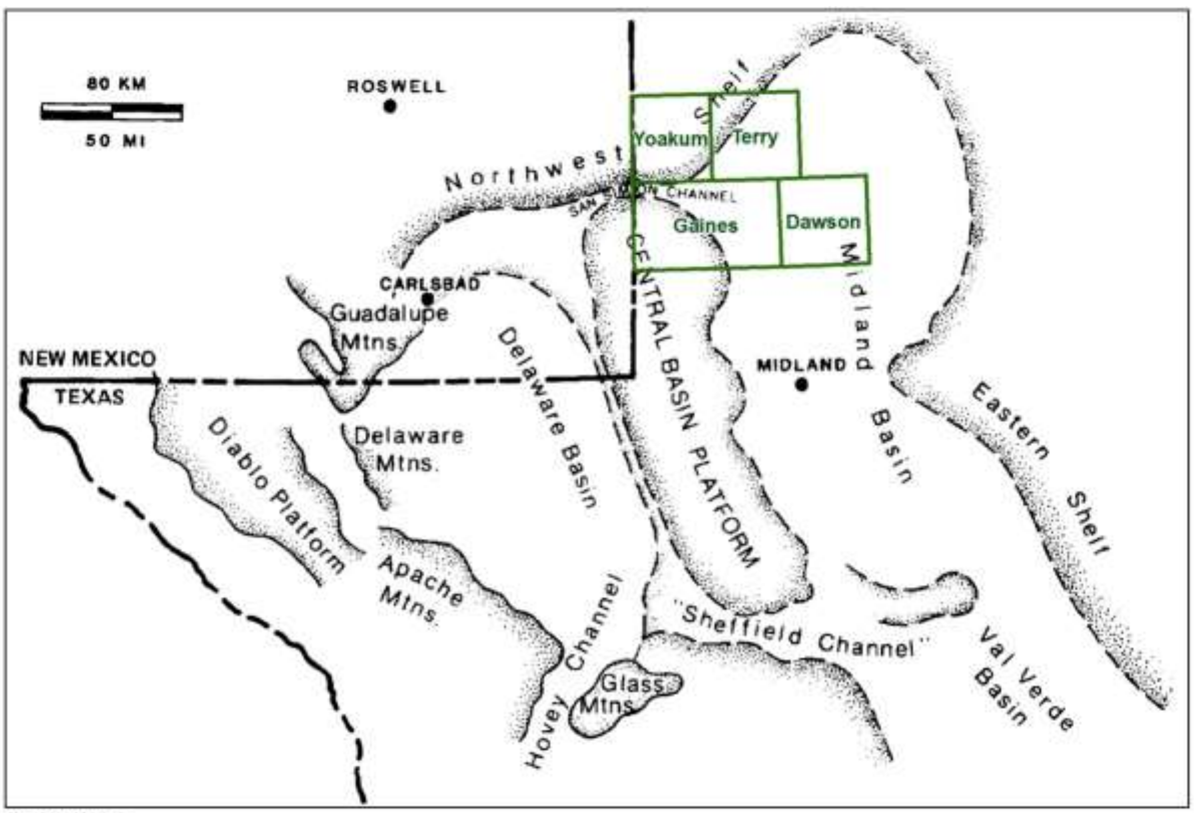
Throughout the Permian period, the Central Basin Platform was the site of carbonate shelf and shelf/margin deposition on top of a basement uplift that separated the deep Delaware Basin on the west and the shallower Midland Basin on the east. Broad and extensive carbonate shelves developed along the eastern, northern and northwest margins of the Midland and Delaware Basins. Consequently the Permian age stratigraphic section, which spans Wolfcampian, Leonardian, and Guadalupian time, is dominated by carbonate shelf deposition. (Ward et al., 1986)

The four-county area addressed by this San Andres ROZ “fairway” resource assessment includes four distinct paleogeographic features of the Permian Basin:

- Northwest Shelf,
- San Simon Channel,
- Central Basin Platform, and
- Midland Basin and its prograding carbonate shelf margins.

These four prominent features are shown on Exhibit 2-2, which illustrates the configuration of the Permian Basin during the initial deposition of the San Andres Formation.

Exhibit 7.3-2 Key Permian Basin Paleographic Features



Source: Ward, 1986.

The San Andres Formation in the study area is 1,200 feet to 1,600 feet thick. It is underlain by the Glorieta/ San Angelo Formation and overlain by the Grayburg and other formations of the Upper Permian Artesia Group, Exhibit 7.3-3.

Exhibit 7.3-3 Stratigraphic Column: Permian Interval of the Permian Basin

SYSTEM		Series	*Permian Basin - Northwest Shelf*	
PERMIAN	UPPER	Ochoan	*Absent*	
		Guadalupian	Tansill	Artesia Group
			Yates	
			Seven Rivers	
			Queen	
			Grayburg	
			San Andres	Upper
	LOWER	Leonardian		Lower
			Glorieta/ San Angelo	
			Upper Clearfork	Clearfork Group
			Tubb	
			Lower Clearfork	
			Abo	
		Wolfcamp	Wolfcamp	

JAF2015_039.PPT

Source: Modified from Figure 3b, Stratigraphic nomenclature for the Permian section in the Permian Basin in: Dutton, S.P. and others, 2004, Play Analysis and Digital Portfolio of Major Oil Reservoirs in the Permian Basin: Application and Transfer of Advanced Geological and Engineering Technologies for Incremental Production Opportunities, Texas Bureau of Economic Geology, work performed under contract DE-FC26-02NT15131.

The San Andres Formation is characterized as an overall shallowing-upward sequence of shelf carbonates. Carbonate lithofacies include shelf slope limestones of the Lower San Andres, dolomitized grainstones, fossiliferous wackestones, packstones and boundstones of the outer and middle shelf; and dolomudstones, algal deposits and evaporate deposits of exposed tidal flats of the inner shelf. Superimposed upon the upward-shoaling San Andres carbonate succession are smaller scale stratigraphic sequences and lateral heterogeneity, the result of fluctuating water depth due to higher frequency transgressive-regressive depositional cycles and local paleotopography. (Ruppel et al., 1995) (Kerans et al., 1994)

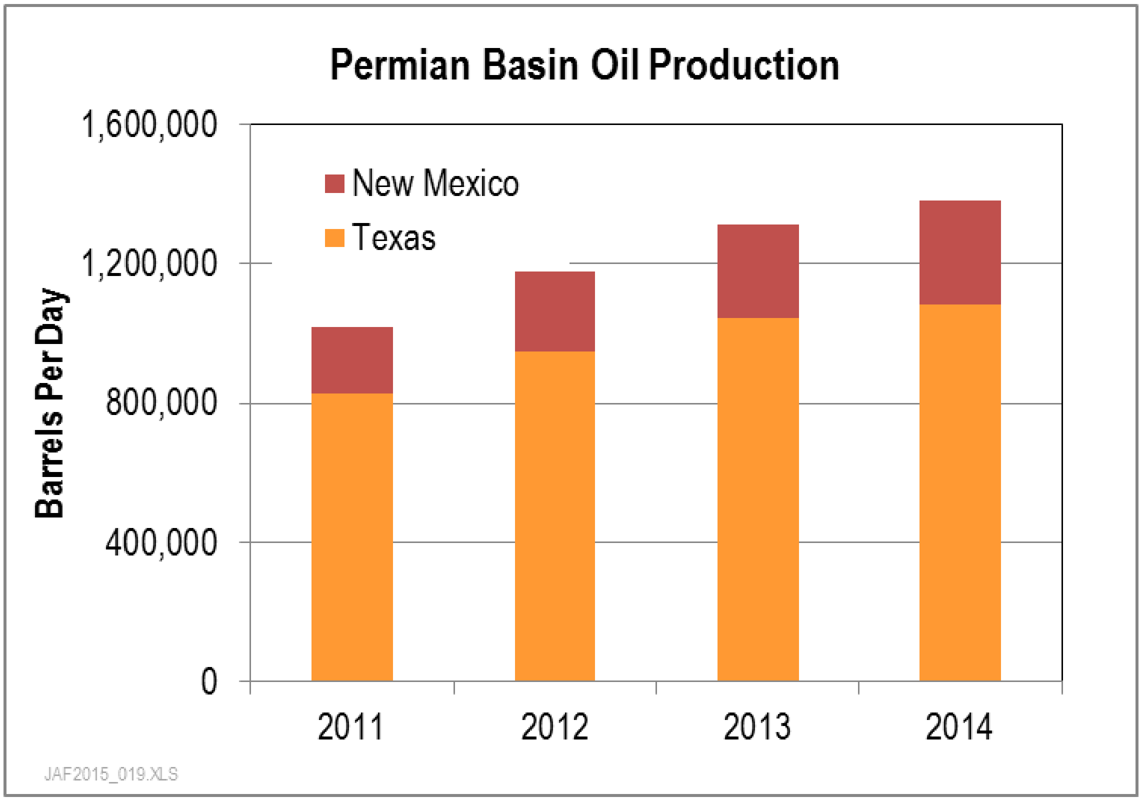
In the four-county study area, notable reservoir porosity and the ROZ interval occurs in the Middle to Lower San Andres, in dolostones originating as subtidal and intertidal deposits of the middle and inner shelf, chiefly as shoals and low relief banks/reefs, lagoons, storm deposits, and tidal flats. (In other portions of the Midland Basin notable reservoir porosity and the ROZ interval occurs in the Upper San Andres.) The multiple stratigraphic sequences within the overall shoaling-upward framework of the San Andres compartmentalize the porous reservoir. Potential barriers to flow are provided by dolomudstones at the base of individual depositional sequences and, at the top of individual sequences, by interbedded anhydrite, siltstone, low porosity dolomite and subaerial exposure features that may be present. (Cowan and Harris, 1986)

Permeability development is heterogeneous but often increases upward within individual stratigraphic sequences. Permeability development is influenced by the type of primary pore system and by the complex post-depositional diagenesis of the San Andres formation, which included multiple episodes of dolomitization, subsequent leaching of dolomite, occlusion of porosity by anhydrite, and subsequent alteration of anhydrite. Principal pore types recognized in the Lower San Andres include interparticle and intercrystalline porosity, moldic pores, and vugs of various sizes. (Grant et al., 1994) Unique pore types related to breccias, boundstones and fenestrate rock fabrics can also be locally important. (Holtz, 2002)

7.3.1 Historical Oil Production

The Permian Basin has been, and remains, a significant producer of oil and natural gas, with both oil and natural gas production increasing in recent years, Exhibit 7.3-4. The development of the basin's shale and tight sand resources along with expanded applications of CO_2 -EOR have provided the majority of oil production growth.

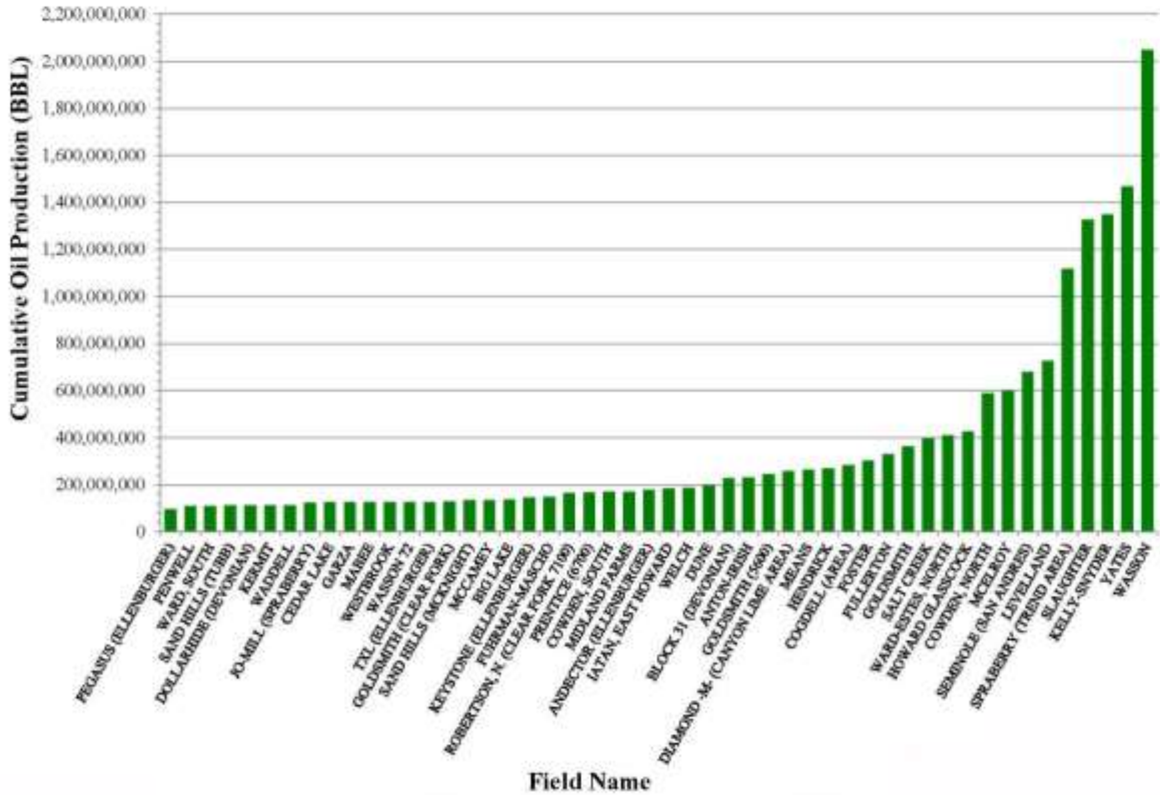
Exhibit 7.3-4 Growth of Permian Basin Oil Production



Source: Advanced Resources International, 2015. Railroad Commission of Texas and other sources.

During its 90 plus years of development, the Permian Basin has produced 30 billion barrels of oil and 75 Tcf of natural gas from more than 7,000 oil and gas fields. (Railroad Commission of Texas, 2015) A significant portion of the oil produced to date has been from a series of major oil fields, such as Wasson, Yates, Kelly-Snyder, Slaughter, Levelland and Seminole, Exhibit 7.3-5. Many of these major oil fields are currently being developed and produced with the application of CO_2-EOR.

Exhibit 7.3-5 Top 50 Highest Producing Permian Basin Oil Fields (as of March, 2013)



Source: Railroad Commission of Texas, March 2013

The Permian Basin San Andres ROZ “fairway” resource, as addressed by this assessment, represents the extensive areas outside the structural closure of these major oil fields. As such, our study addresses an overlooked and previously undefined domestic oil resource. The CO_2-EOR projects in the ROZ “fairway” are true “Greenfields”, areas that have not experienced prior conventional primary or secondary oil recovery.

7.3.2 Permian Basin Residual Oil Zone (ROZ)

The San Andres ROZ Resource

Permian Basin operators have known for some time about the presence of low oil and high water saturation intervals below the Main Pay Zones of their San Andres oil fields. Testing of these low residual oil intervals typically led to the production of large volumes of water with, at best, low, non-commercial volumes of oil.

Initially, the reservoir engineering community judged these low oil saturation intervals below the Main Pay Zone to be limited in size "transition" zones created by capillary forces. In contrast, to the exploration geologist community, these low oil saturation intervals and fairways were viewed as the remnants of oil migration pathways that might indicate the direction and location of new, structurally confined oil fields.

The pioneering work by Mr. Steve Melzer, assisted by the University of Texas Permian Basin (UTPB) and Dr. Robert Trentham, helped establish that these low residual oil saturation settings consisted of residual oil left behind by very slow, Tertiary-age hydrodynamic flow ("mother nature's waterflooding") through the San Andres interval of the Permian Basin, giving birth to the term "the ROZ".(Melzer, 2006), (Melzer et al., 2006) As significant, Melzer and Trentham, assisted by others, established that ROZs existed not just under existing oil fields but also in laterally extensive "fairways" beyond the structural closure of the oil fields in the Permian Basin. The work described herein can assist with defining the enormity of the "paleo" trap within the San Andres Fm at the end of the Cretaceous period, prior to the onset of Tertiary-age hydrodynamics. (Trentham et al., 2012)

As expected, industry's initial efforts targeted the ROZ intervals below existing oil fields such as at Wasson, Seminole and Goldsmith. Early laboratory and field tests showed that the application of high pressure, miscible CO_2-EOR could mobilize this residual oil. Based on this positive information, industry began deepening existing wells, as well as drilling new wells, into the ROZ below their San Andres oil fields and started injecting high pressure CO_2 to produce this residual oil. In geologically favorable settings, these initial efforts demonstrated potential for commercial levels of oil production.

7.3.3 Characteristics of the San Andres ROZ

The primary oil producing interval of the San Andres Formation in the study area is porous dolomite located approximately 400 to 500 feet below the top of the San Andres Formation.

This section, referred to as the ‘Main Pay Zone’ (MPZ) and defined by the closure of the structural trap above the ROZ, can have a gross thickness of 100 to 200 feet and consist of multiple porous dolomite intervals, typically ten to thirty feet thick on well logs, interbedded with mudstone, siltstone and anhydrite.

Below the MPZ (where present) and its producing oil/water contact is a thick Lower San Andres section of porous and permeable dolomite often described as “massive” dolomite or “pervasively dolomitized.” This interval comprises the Residual Oil Zone (ROZ). If no MPZ is present, the entire porous San Andres interval has been swept and is called a “green field” ROZ.

In the four-county study area, the porous dolomite of the ROZ interval ranges from 100 feet to more than 600 feet thick. (In the eastern portion of the study area, the pervasive dolomite interval, while even exceeding 600 feet thick, loses its oil saturation in the lower portion of the ROZ. It is postulated that these lower sections never possessed oil during the Cretaceous “paleo” trap.

The porous San Andres ROZ is indicated by a drilling break on mud logs and by a distinctive increase in porosity and corresponding decrease in resistivity on open-hole logs. Hydrocarbon shows are common while drilling through the Lower San Andres ROZ including gas shows, oil stain, fluorescence and a streaming ‘cut’ of oil from drill cuttings and core. Typically, the ROZ interval has bright fluorescence in the upper portion and duller fluorescence in its deeper section, suggesting the oil properties may be changing in the ROZ interval. Oil saturations in conventional whole core commonly range from below 20 percent to above 30 percent in the ROZ interval. Upon further testing, the interval almost always produces water and little to no oil.

In the four-county study area, the lowermost boundary of the ROZ is typically determined by the change in lithology from dolomite to limestone (if Lower San Andres limestone is present) or, if limestone is not present, by the top of the Glorieta Formation. Distinct differences in calculated porosity and oil saturation are often observed between the upper part of the ROZ interval, and the lower ROZ dolomite located above the San Andres limestone or the Glorieta Formation. To capture these differences, our study has divided the San Andres ROZ into two informal intervals: ROZ “1,” corresponding to the upper part of the Lower San Andres porous dolomite, and ROZ “2”, corresponding to the lower part.

Exhibit 7.3-6 is a two-well cross-section showing the San Andres Formation on the Northwest Shelf of the Permian Basin in Yoakum County and the San Andres Formation 27 miles to the southeast near the eastern edge of the Central Basin Platform. This two-well cross-section illustrates characteristics of the San Andres ROZ “fairway” interval addressed by this resource assessment.

Both wells in Exhibit 7.3-6 show log-calculated oil saturation in the ROZ interval. Well No. 1, located within the structural closure of a producing San Andres field, has a thick, well-developed Main Pay Zone (MPZ) with a higher quality ROZ resource interval located in the upper ROZ (ROZ “1”) immediately below the MPZ. In this well, the entire Lower San Andres is comprised of porous dolomite with the base of the ROZ defined by the top of the underlying Glorieta Formation.

Well No. 2 is located outside the structural closure of a major producing San Andres Field. This well shows a thin zone of higher oil saturations at the top of the San Andres ROZ interval that may correspond to a limited MPZ. In this well, the higher quality ROZ resource occurs deeper in the lower San Andres porous dolomite, in ROZ “2”.

Well No. 1 provides an example of the ROZ resources that have been excluded from this resource assessment, because the well is within the structural closure of a producing San Andres field. Well No. 2 provides an example of the ROZ resources that are included in the resource assessment, because the well is outside the structural closure of a San Andres field, even though the well may hold a modest volume of apparent mobile oil saturation at the top of the San Andres ROZ interval.

Exhibit 7.3-6 Stratigraphic Cross-Section Illustrating the San Andres ROZ "Fairway" Resources of Yoakum and Gaines Counties

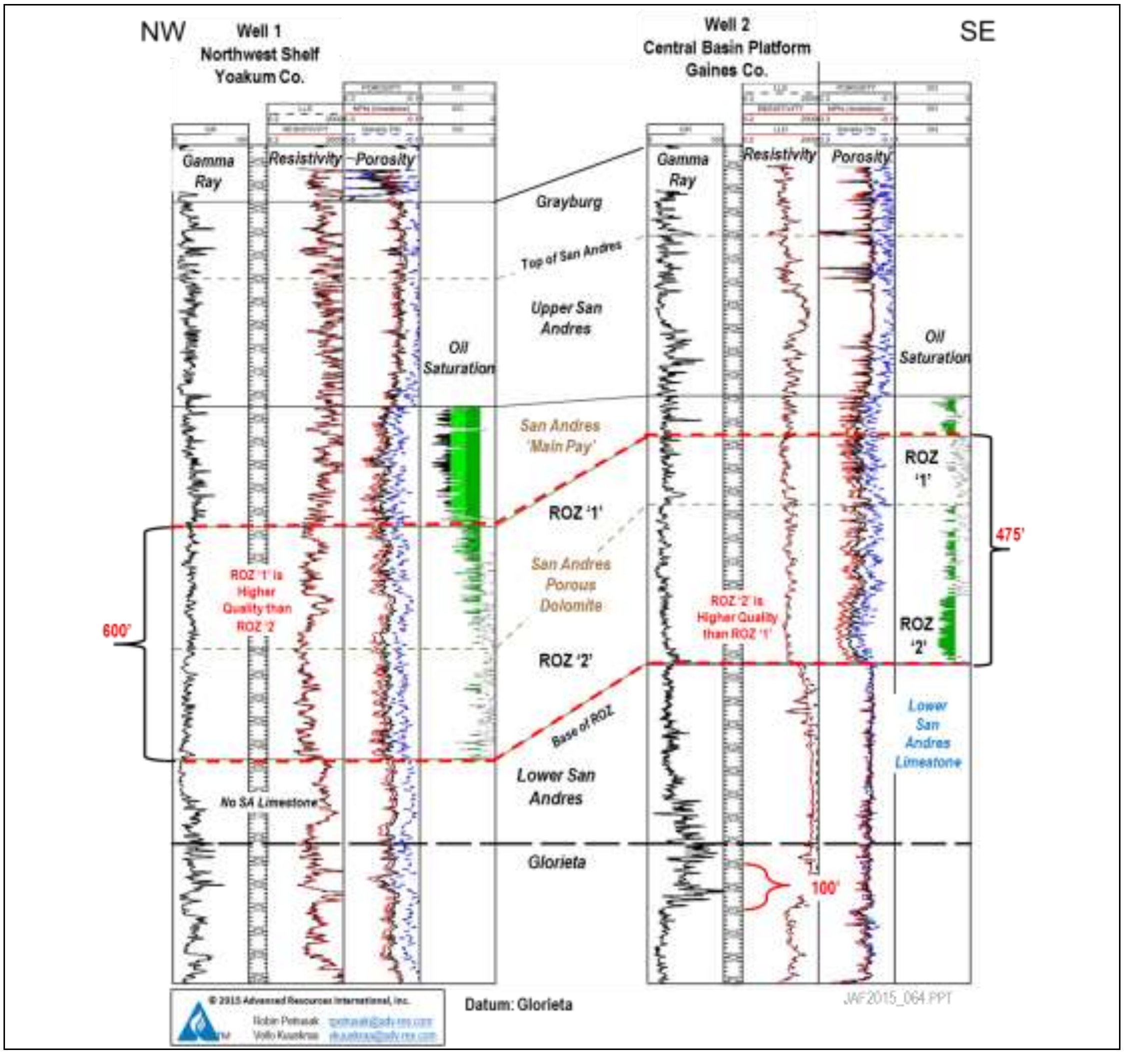
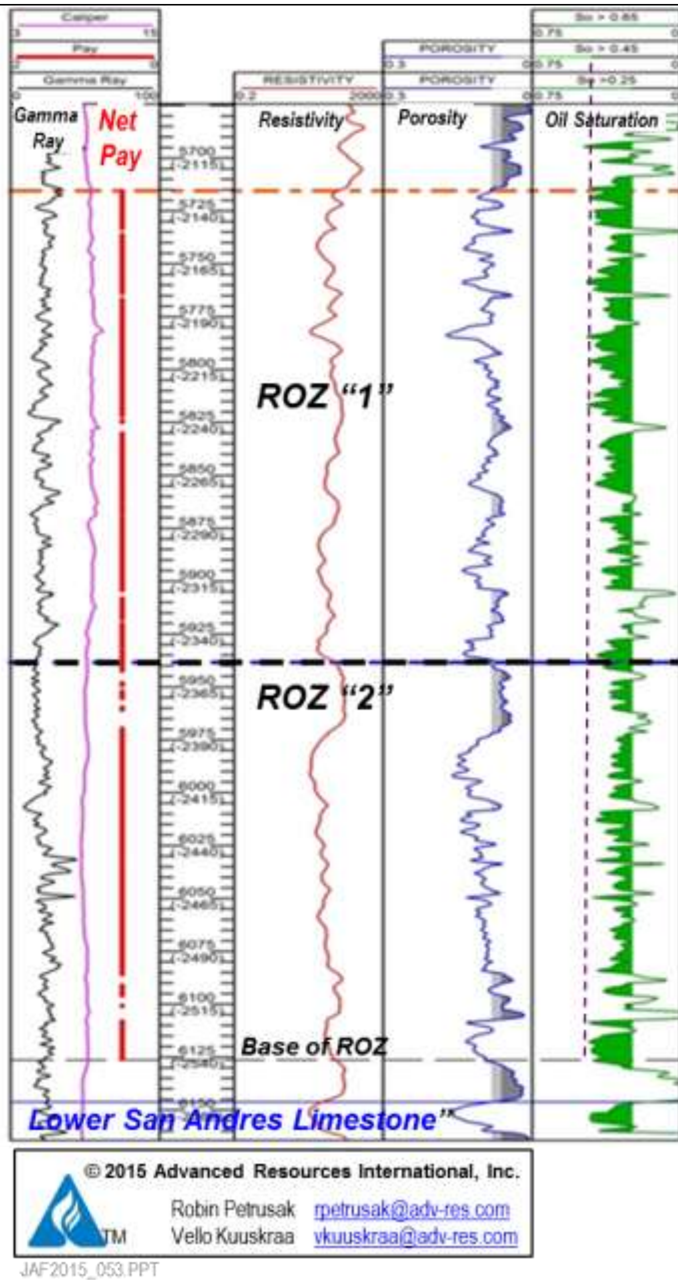


Exhibit 7.3-7 illustrates a typical ROZ oil saturation profile for a study well without a San Andres "main pay." The calculated oil saturation of net pay shown in Exhibit 7.3-7 (shaded in green) ranges from 25 % to 45 %. A dashed vertical line corresponding to an oil saturation of 45 % helps to illustrate that the calculated residual oil saturation is highest in the upper ROZ and declines with depth through the ROZ. In this example, ROZ "1" and ROZ "2" are separated by a low porosity interval in the middle of the ROZ. The base of the ROZ is defined by another low porosity interval, as well as by a change in lithology from dolomite to lower San Andres limestone.

Exhibit 7.3-7 Typical Oil Saturation Profile for the San Andres ROZ "Fairway" in the Four-County Study Area



The dolomite of the lower ROZ (ROZ "2") may appear on well logs to be thinner bedded, more "shaley" (higher gamma ray) and may be separated from the dolomite of the upper ROZ (ROZ "1") by an apparent shale zone or low porosity interval. Exhibit 7.3-7 illustrates how the informal division of the ROZ into an upper and lower ROZ (ROZ "1" and ROZ "2") proved useful for organizing the OIP calculation. In this example, the net pay of ROZ "1" has higher average residual oil saturation compared to ROZ “2” (34 % vs. 32 %), and the net pay of ROZ “2” has higher average porosity compared to ROZ “1” (10.2 % vs. 9.4 %). However, due to the greater thickness of net pay in ROZ “1,” nearly 60 percent of the ROZ resource in this well is located in the upper ROZ.

7.3.4 ROZ “Fairway” Concept

The concept of post-entrapment movement of oil following basin-scale tectonic activity was proposed by Mr. Steve Melzer in 2006, as an alternative to the traditional concept of capillary forces and interfacial tension, to explain widespread observations of significant residual oil saturations beneath the producing oil/ water contact in San Andres oil fields.

Mr. Melzer proposed three mechanisms for the formation of post-entrapment, regional-scale residual oil zones. These include basin tilt, breached and reformed reservoir seals, and altered hydrodynamic flow in response to regional and basin-scale tectonics. The dominant ROZ mechanism for the Permian Basin was judged to be the third type, in which altered hydrodynamic conditions due to uplift caused lateral flushing by meteoric water of the lower oil column in the San Andres Formation. This characterization of the San Andres ROZ in the Permian Basin is supported by other evidence such as tilted oil/water contacts beneath the major oil fields, the recognition of widespread alteration and leaching of San Andres reservoirs and biodegradation and displacement of San Andres oil. (Steuber, 1998; DuChene, 2013; Vance, 2014)

As miscible CO_2 flooding of the ROZ below existing oil fields began to be established as commercially viable, (Honarpour et al., 2010) Dr. Trentham and Mr. Melzer proposed that the ROZ “fairway” areas of the San Andres Formation in the Permian Basin might also be favorable for development. Their hydrodynamic extensive modeling work, published in 2012, identified hydrodynamic flow “fairways” in the San Andres of the Permian Basin where extensive “greenfield” ROZs would be expected, i.e. residual oil where no “main pay” zones are present.

The pathway for movement of water through the “fairways” is reservoir quality rock. If mobile oil is present, the lateral flushing process forms a ROZ. If structural closure is also present, some of the primary oil can be isolated from the flushing process and a main pay zone (MPZ) remains. If no isolated structural (or stratigraphic) trap is present, the entire primary oil accumulation is swept, leaving a residual saturation behind with no “main pay” accumulation.

A thorough discussion of the geographic distribution of ROZ “fairways” is provided by Dr. Trentham, which describes the pathways of eastward migrating meteoric waters moving down dip from recharge areas west of the western margin of the Northwest Shelf. A key finding is that the lateral flushing occurred relatively rapidly along aquifer pathways that were different from the pathways for oil migration into the reservoirs. The hydrodynamic flow regime is also thought to have contributed, in some areas, to episodic migration of oil, first out of structural closures and later a post-flushing “reverse” migration of oil back into structures.

7.3.8 Estimating ROZ “Fairway” Resources

Overview of Methodology

The San Andres “ROZ “fairway” resource study assembled logs for 123 wells drilled in the four-county area, concentrating on logs that fully penetrated the San Andres ROZ interval below the main San Andres pay zone. From this larger data set, digital logs (LAS files) were acquired for 90 wells. The digital logs were analyzed using IHS Petra workstation software to establish the key volumetric reservoir properties and calculate the San Andres ROZ “fairway” oil in-place in this four-county, West Texas portion of the Permian Basin.

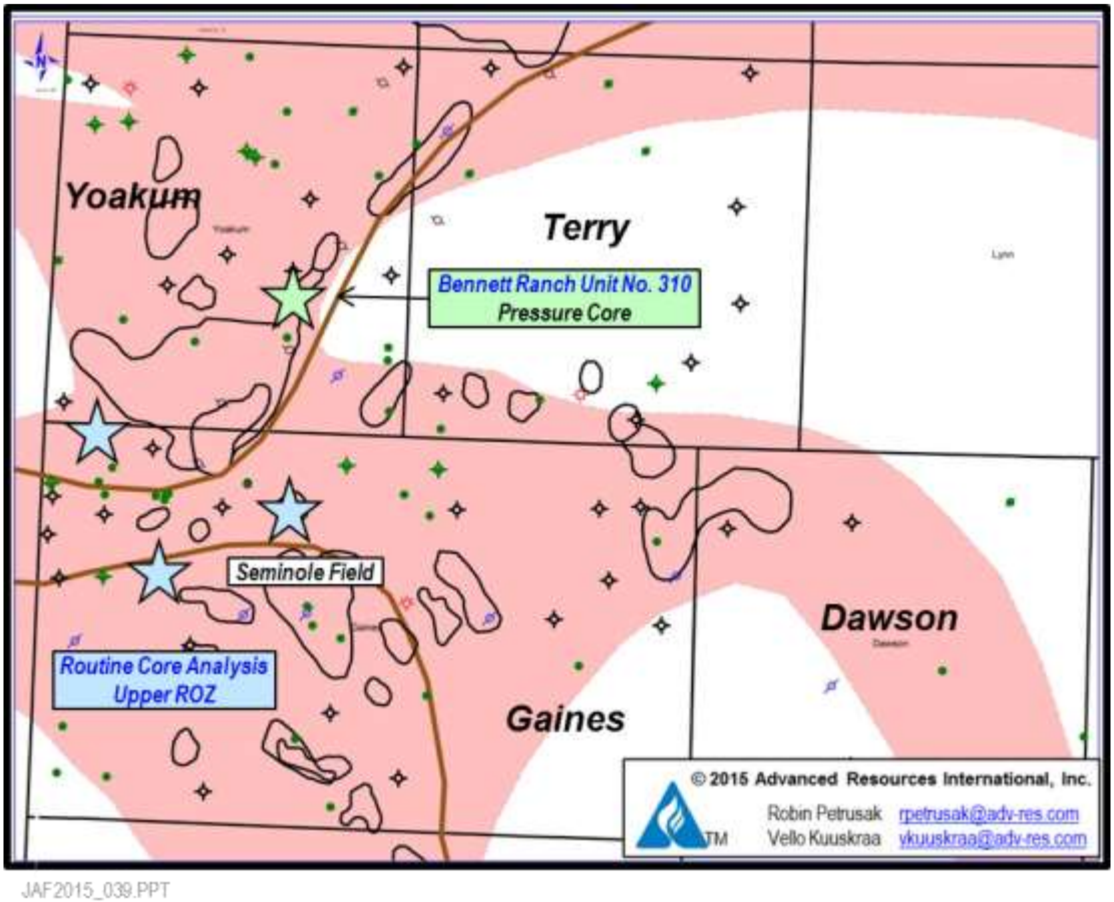
A key objective of the quantitative analysis was to apply as consistent a log analysis approach as possible to the ROZ across the entire study area. Observed variations in the quantity and quality of resources could then be attributed to actual change in the ROZ resource across the area rather than the log analysis approach.

Working cross-sections were constructed using all the study wells to correlate geophysical log characteristics and guide our understanding of reservoir thickness, lithology and stratigraphic continuity within the San Andres ROZ. Based on observations from these cross-sections, each county in the study area was divided into three to five geologically similar partitions, corresponding to features in the study wells such as apparent porosity, total dolomite thickness, calculated oil saturation and log character (particularly the gamma ray and resistivity logs.) Selected cross-section examples are provided in the discussion of individual county results later in this report.

7.3.9 Data Sources

Exhibit 7.3-8 shows the location of the study wells and the core data used for this study. The log data were calibrated to core data available from the San Andres ROZ “fairway” interval in this four-county area. Core data for the upper ROZ interval were available from four previously drilled wells, as shown on Exhibit 7.3-8.

Exhibit 7.3-8 Location of Data for Four-County San Andres ROZ "Fairway" Resource Assessment



Source: Advanced Resources International, 2015.

Three of the cores included routine analyses of whole core and plugs, which provided data on porosity, grain density, fluid saturation and lithology for the upper ROZ. One of the cores, at the Bennett Ranch Unit of the Wasson oil field, included pressure core and other whole core data for a 210-ft interval from 5,175-5,385 ft. (U.S. DOE, 1982). This key core study provided porosity, fluid saturations, grain density, and electrical properties data for establishing the important Archie parameters of 'm' and 'n' subsequently used in the analyses of the 90 San Andres logs in the study area.

7.3.10 Computing Porosity in the ROZ

Porosity was computed using all available logs, including compensated neutron, density, and sonic logs. Lithology corrections and environmental corrections were applied as needed; bad values and obvious shale zones were excluded from the analysis. Compensated neutron and sidewall neutron logs were corrected for dolomite, which reduced the compensated neutron porosity by approximately 6 to 8 porosity units and the sidewall neutron porosity by 1 to 3 porosity units. Standard published dolomite log corrections were used in the analysis of all logs.

Density porosity was calculated from bulk density using a matrix density of 2.85 to 2.83 g/cc (based on core data) and a fluid density of 1.05 g/cc. Sonic porosity was computed using the Wylie relationship and fluid travel time of 188 □-sec/ft. For most wells throughout the study area, matrix travel time of 43 micro-sec/ft was used to compute sonic porosity. This value produced the best calibration to the available core porosity data from the northern Central Basin Platform area. For wells with multiple porosity logs, the best available porosity log was selected for calculating oil saturation. For most wells, this was a density-neutron cross-plot porosity log.

7.3.11 Computing Oil Saturation in the ROZ

The water saturation (Sw) in the ROZ was computed for the 90 log data set using the classic Archie model:

$$\mathbf{Sw^n = ((a \times Rw)/(Rt \times \phi^m))}$$

Oil saturation (So) at reservoir conditions was computed as 1-Sw. The parameters used for the Archie equation are defined and summarized in Exhibit 7.3-9.

The calculation of water saturation, Sw, is most sensitive to porosity and the parameter ‘m’, cementation exponent. The parameter ‘n’, saturation exponent, is also important for pore systems that may not be entirely water-wet. The parameters ‘m’ and ‘n’ are commonly assumed to be ‘2.0’ in carbonates. Laboratory derived values of ‘m’ are frequently higher than 2.0 for carbonate pore systems with vugs and moldic porosity, and laboratory-derived values for ‘n’ may range from 1.4 to 4 or greater (for oil wet reservoirs). While inputs for the porosity calculation and Archie equation vary areally, as described in Exhibit 7.3-9, for a single well, the parameters used for the calculation of porosity and Sw are the same.

Exhibit 7.3-9 Input Parameters for Calculating Oil Saturation in the ROZ

Porosity Φ	Study wells were selected with available open hole neutron, density, and/or sonic logs. Lithology-corrected density-neutron cross-plot porosity log was most commonly used.	Density porosity: used matrix grain density of 2.85 g/cc for NW Shelf & northwest CBP wells. Used 2.83 g/cc for most of CBP and Midland Basin. Used fluid density of 1.05 g/cc Sonic porosity: Used matrix and fluid travel times of 43 μ-sec/ft and 188 μ-sec/ft for most wells. Varied the matrix travel time from 41 μ-sec/ft in the extreme west & north of study area to 46 μ-sec/ft. in select areas of the Midland Basin.
Archie Parameters	‘m’ =cementation exponent; ‘n’ = saturation exponent; ‘a’ = further correction for tortuosity of electrical pathway	Used ‘a’ = 1 (common default for carbonates). Used ‘m’ & ‘n’ = 2.3 for northern Yoakum, Terry, Dawson & eastern Gaines (Midland Basin). Used ‘m’=2.3, ‘n’= 3.4 for Gaines CBP. Used ‘m’=2.3, ‘n’= 3 for Gaines in the San Simon Channel area, northern Gaines (NW Shelf) and southern Yoakum (NW Shelf).
Rw	Regional formation water salinity values for the San Andres were used to compute Rw at formation temperature.	Average salinity values range from 62,800 ppm (southern Gaines) to more than 190,000 ppm (northwest Yoakum). Rw values used for log analysis range from 0.03 to 0.07 ohm-m.
Rt	Deep resistivity or ‘Rt’ log	Used deep reading resistivity log, corrected for invasion where needed. Used ‘Rt’ log if available.

Values for ‘m’ and ‘n’ for the Northwest Shelf area were selected based on special core analysis data published for the San Andres porous dolomite from the Bennett Ranch Unit at Wasson Field. The value of ‘n’ selected for the Central Basin Platform (CBP) area is an empirical value which calibrates the oil saturation calculation from three logs for Seminole Field to the range of published oil saturation values and estimated OIP available for the San Andres ROZ at Seminole Field. This empirical ‘n’ value is further supported by some of the laboratory-derived values of ‘n’ from the Bennett Ranch core study that contains values greater than ‘3’. Data on formation water salinity for computing Rw were obtained from a basin-wide compilation and analysis of water samples from oil and gas fields by the Texas Water Development Board. (Texas Water Development Board, 1972)

7.3.12 Computing Oil In-Place and High-Grading the ROZ Resource

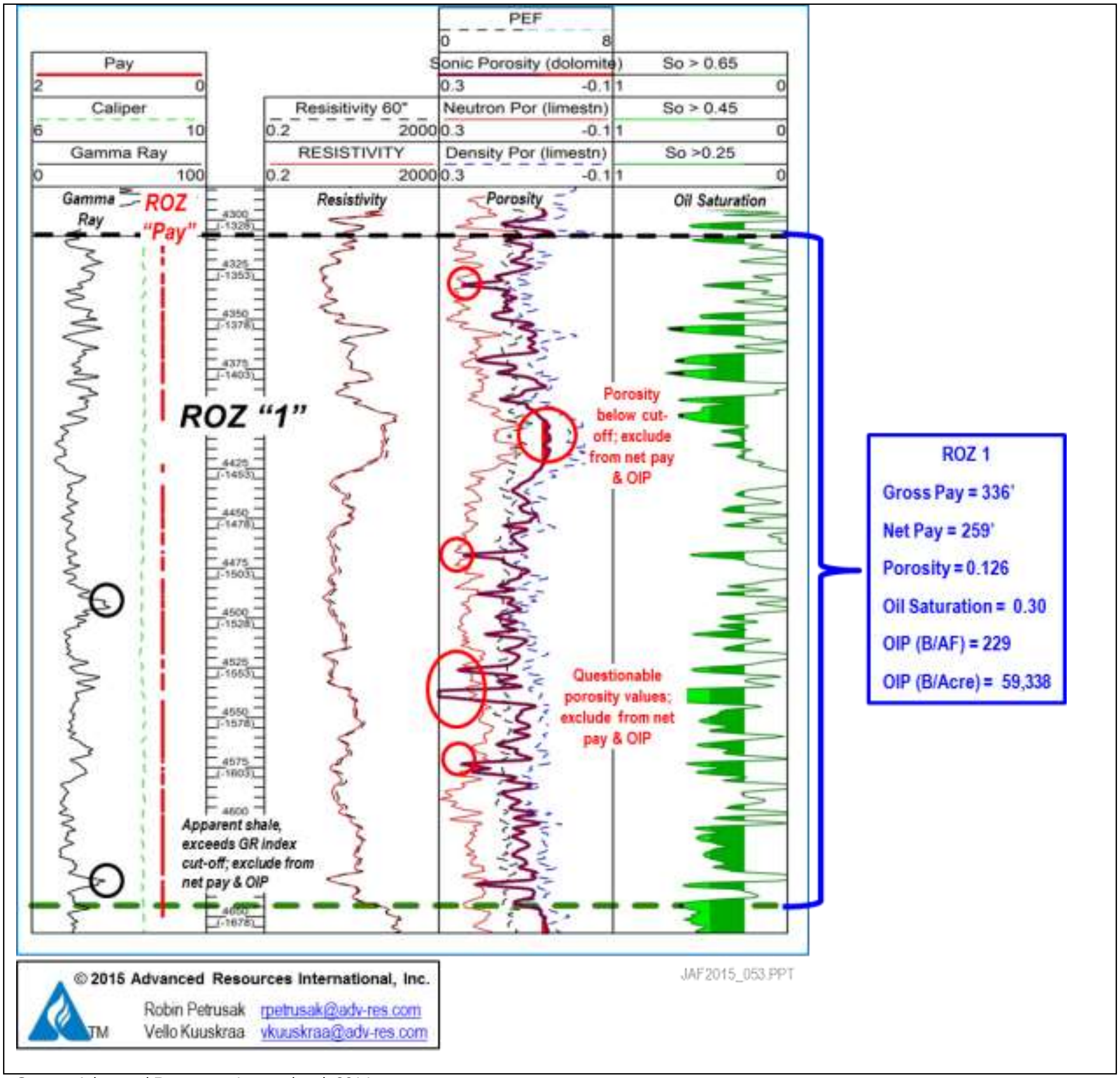
After porosity and oil saturation were calculated for each well, a porosity cut-off of 6 percent was applied to define net 'pay'. No oil saturation cut-off was applied. Questionable high porosity and oil saturation values were excluded from net pay. A gamma ray index was computed and applied to exclude apparent shale zones from net pay. For most wells, a gamma ray index cut-off of 0.4 was applied.

After all porosity cut-offs and pay exclusions were applied, the calculated net pay intervals were flagged. Total net pay was summed for the ROZ interval and the average porosity of net pay and the average oil saturation of net pay were computed. The value of total net pay, average porosity of net pay, and average oil saturation of net pay were then used to compute oil in-place for the ROZ interval. A partition-specific formation volume of factor (FVF), typically ranging from 1.1 to 1.3, was applied to convert reservoir barrels to stock tank barrels.

Exhibit 7.3-10 shows an example calculation of porosity, oil saturation and net pay for ROZ '1' for a well in Gaines County. In this example, the gross thickness of ROZ '1' is 336 feet. Total net pay is 259 feet, defined by the porosity cut-off of 6 percent. The average porosity of net pay is 12.6 % and the average oil saturation of net pay is 30 %. Total oil in-place is 59,338 barrels/acre or 229 barrels/acre-ft of net pay.

The ROZ "fairway" resources were further analyzed to establish volumes of "higher quality" and "lower quality" resources. A "higher quality" ROZ resource was established for areas where the average computed net pay log values are greater than 8 % for porosity and 25 % for oil saturation. If either the average porosity or the average oil saturation of net pay is below the above cut-off values, then the ROZ resources in the area represented by the study well are characterized as "lower quality." For example, if the ROZ 'pay' in a well has an average porosity value of 12.3% and an average oil saturation of 24%, the ROZ resource in the entire area represented by that study well is characterized as "lower quality" based on oil saturation.

Exhibit 7.3-10 Identifying the ROZ "Fairway" Resource and Computing Oil In-Place



Source: Advanced Resources International, 2014.

The use of additional logs and data points would, no doubt, refine the resource assessment values, allowing areas of "higher quality" and "lower quality" ROZ resource to be determined with greater accuracy.

7.3.13 Size and Quality of the 4-county San Andres ROZ "Fairway" Resource

Our assessment of the San Andres ROZ "fairway" current resources in Gaines, Yoakum, Terry and Dawson counties of West Texas identifies 111.9 billion barrels of oil in-place. Much of the in-place ROZ "fairway" resource in this four-county area is "higher quality", estimated at 76.7 billion barrels of oil in-place, offering promise for commercially viable development with by-product storage of CO_2, Exhibit 7.3-11.

Exhibit 7.3-11. In-Place San Andres ROZ "Fairway" Resources: Four-County Area of West Texas

County	In-Place Resource		
	Total (B Bbls)	Higher Quality (B Bbls)	Lower Quality (B Bbls)
Gaines	45.5	35.4	10.1
Yoakum	20.7	16.1	4.6
Terry	17.9	10.6	7.3
Dawson	27.8	14.6	13.2
Total	**111.9**	**76.7**	**35.2**

Source: Advanced Resources International, 2015.

- Gaines County, the site of the "Tall Cotton" San Andres ROZ "fairway" CO_2-EOR project, discussed above, holds 45.5 billion barrels of San Andres ROZ "fairway" oil in-place, with nearly 80% of the in-place resource judged as "higher quality".
- The areally extensive Dawson County, with 27.8 billion barrels of San Andres ROZ "fairway" oil in-place, is second in terms of resource size. However, only about half of the in-place resource is "higher quality".
- Yoakum County, holding 20.7 billion barrels of San Andres ROZ "fairway" oil in-place, has about three-quarters of its in-place resource as "higher quality".
- Terry County, with much of its area located outside the previously established borders of the San Andres ROZ "fairway" holds 17.9 billion barrels of San Andres ROZ "fairway" oil in-place, with more than half judged as "higher quality".

7.3A Gaines County

7.3A.1 Geographic and Geologic Setting of the Gaines County ROZ “Fairway”

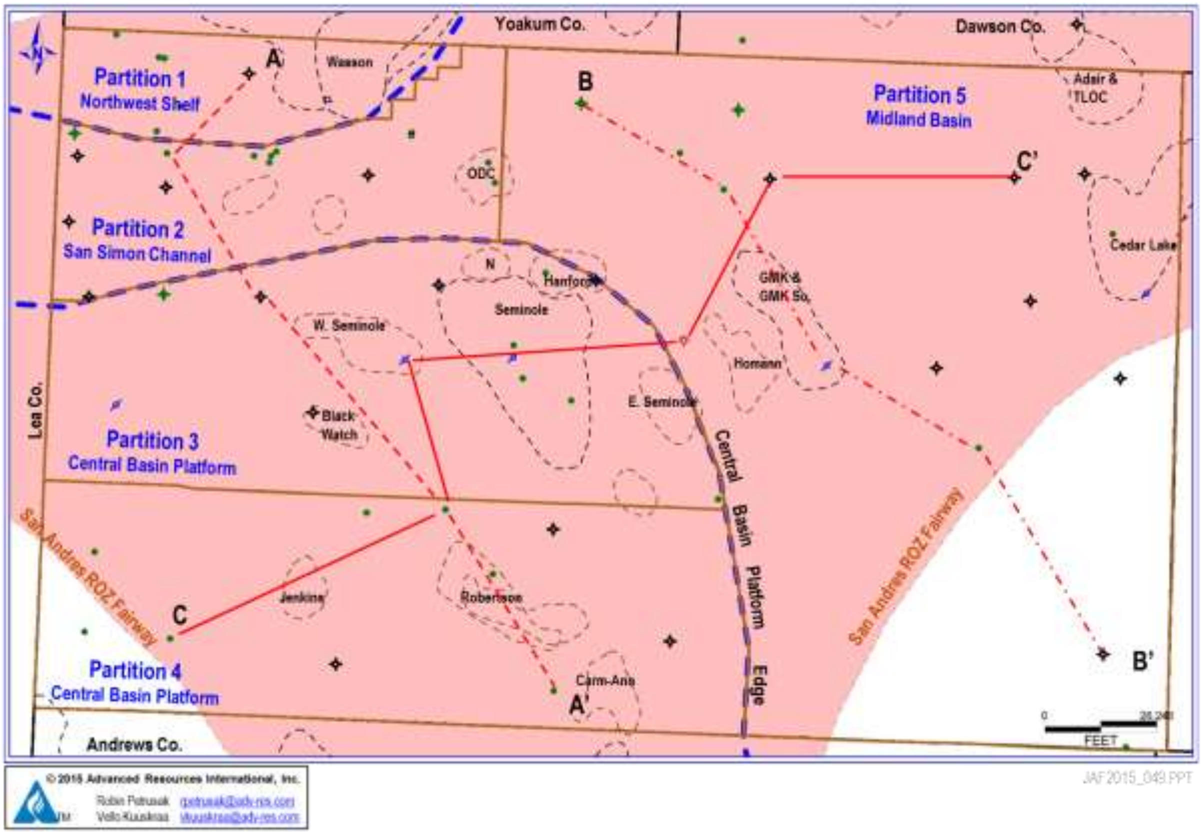
Gaines County, Texas covers a 961,900 acre (1,503 mi^2) area in the western portion of the Permian Basin. Approximately half of the county encompasses the Central Basin Platform, the San Simon Channel, and the southern tip of the Northwest Shelf. The remainder of the Gaines County area is east of these prominent Permian Basin features and is located within the south-eastward prograding Lower and Middle San Andres shelf margins of the Midland Basin.

Gaines County contains numerous San Andres oil fields, including Seminole, Cedar Lake, Robertson, Hanford and GMK, among others. The ROZ resource below these and other existing San Andres oil fields has been excluded from the resource assessment of the San Andres ROZ “fairway” in Gaines County.

Based on the currently mapped boundary of the San Andres ROZ “fairway”, most of Gaines County, with the exception of its southeast corner and a small section in its southwest corner, resides within the previously established ROZ “fairway” boundary.

The Gaines County map, Exhibit 7.3A-1, shows: (1) the location of 39 study wells; (2) the five San Andres ROZ “fairway” partitions established by the study; (3) the boundaries of the previously established San Andres ROZ “fairway”; (4) the outline of the NW Shelf and Central Basin Platform; and (5) the location of three stratigraphic cross-sections featuring the San Andres ROZ. The map also shows the locations of the major San Andres oil fields excluded from the San Andres ROZ “fairway” resource assessment in Gaines County.

Exhibit 7.3A-1 Gaines County San Andres ROZ "Fairway": Geologic Partitions, Major Oil Fields and Study Well Locations



Source: Advanced Resources International, 2015.

7.3A.2 Example Gaines County Cross-Sections

The delineation and characterization of the San Andres ROZ "fairway" interval in Gaines County has drawn on the construction of a series of working cross-sections. Three of these cross-sections are included in this report.

- Gaines Co. Cross-Section A-A' (Exhibit 7.3A-2) provides a NW-SE view of the San Andres ROZ interval starting on the Northwest Shelf, traversing through the San Simon Channel, and ending in the Central Basin Platform.
- Gaines Co. Cross-Section B-B' (Exhibit 7.3A-3) provides a NW-SE view of the San Andres ROZ interval in the Midland Basin.

- Gaines Co. Cross-Section C-C' (Exhibit 7.3A-4) provides a SW-NE view of the variability of the San Andres ROZ interval from the Central Basin Platform to the Midland Basin.

7.3A.3 Interpretation of Gaines County Cross-Sections

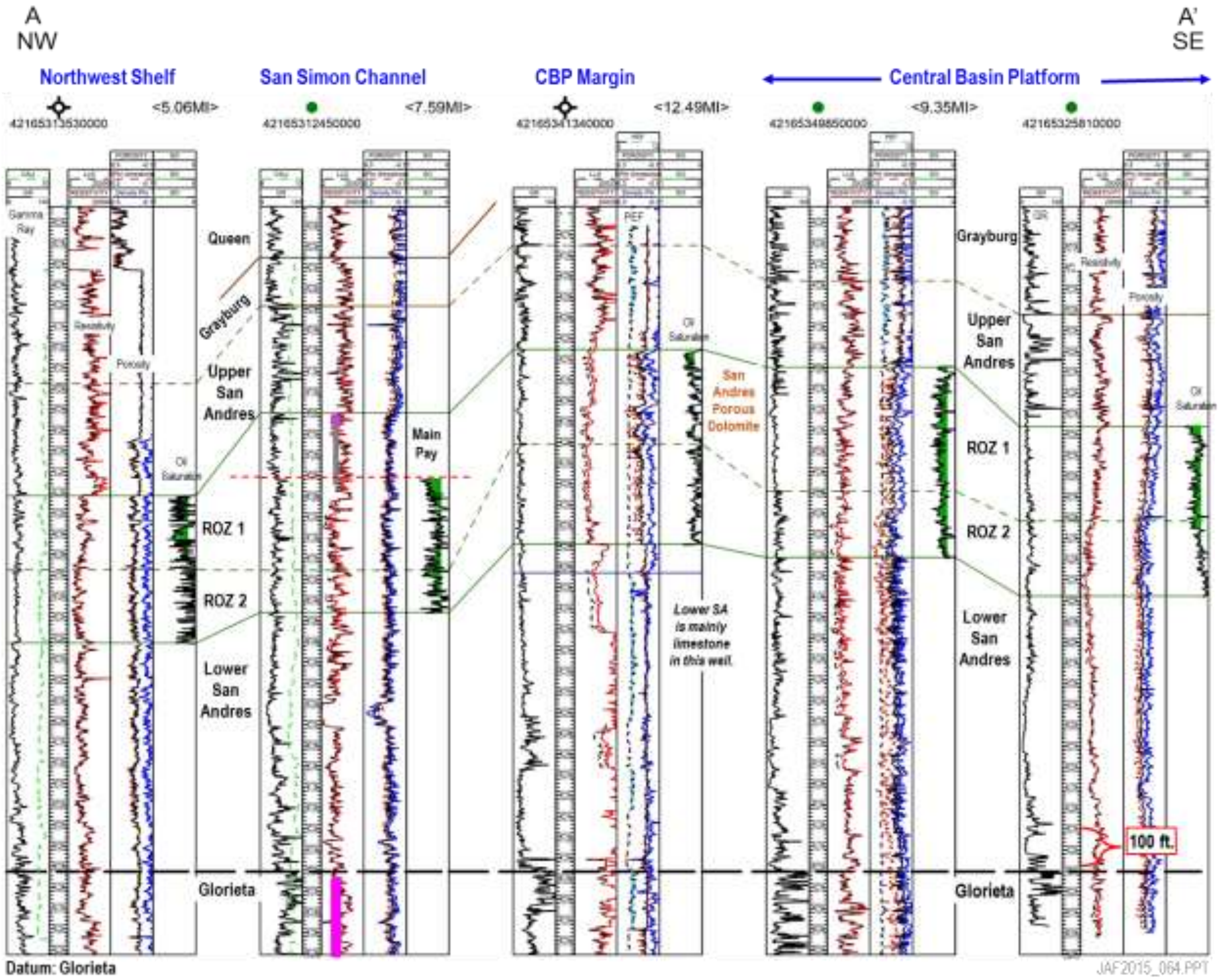
For logs from existing oil fields with a Main Pay Zone, the top of the porous dolomite provides a marker for the top of the Main Pay Zone. For logs from the ROZ "fairway", the top of the San Andres porous dolomite is picked as the top of the ROZ for this resource assessment. The porous dolomite intervals informally designated as ROZ "1" and ROZ "2" are illustrated on the cross-sections.

The cross-sections display gamma-ray and caliper logs in Track 1 on the left. Resistivity logs are shown in Track 2, with the deep resistivity log shown in red. Track 3 shows the porosity logs. Uncorrected neutron porosity (for limestone) is shown in red; uncorrected density porosity (for limestone) is shown in blue. The porosity curve used for the oil in-place calculation is shown in black. This porosity curve represents the "best available" porosity log for the ROZ, which may be a lithology-corrected neutron-density cross-plot porosity log, a lithology-corrected sonic porosity log, or a corrected neutron or density porosity log.

The photo-electric (PEF) curve, if available, is also displayed in Track 3. PEF values greater than "4" are shaded in blue. In the San Andres dolomite above the ROZ, high PEF values greater than "4" likely correspond to anhydrite. Within and below the ROZ interval, high PEF values generally indicate the presence of limestone or dolomitic limestone.

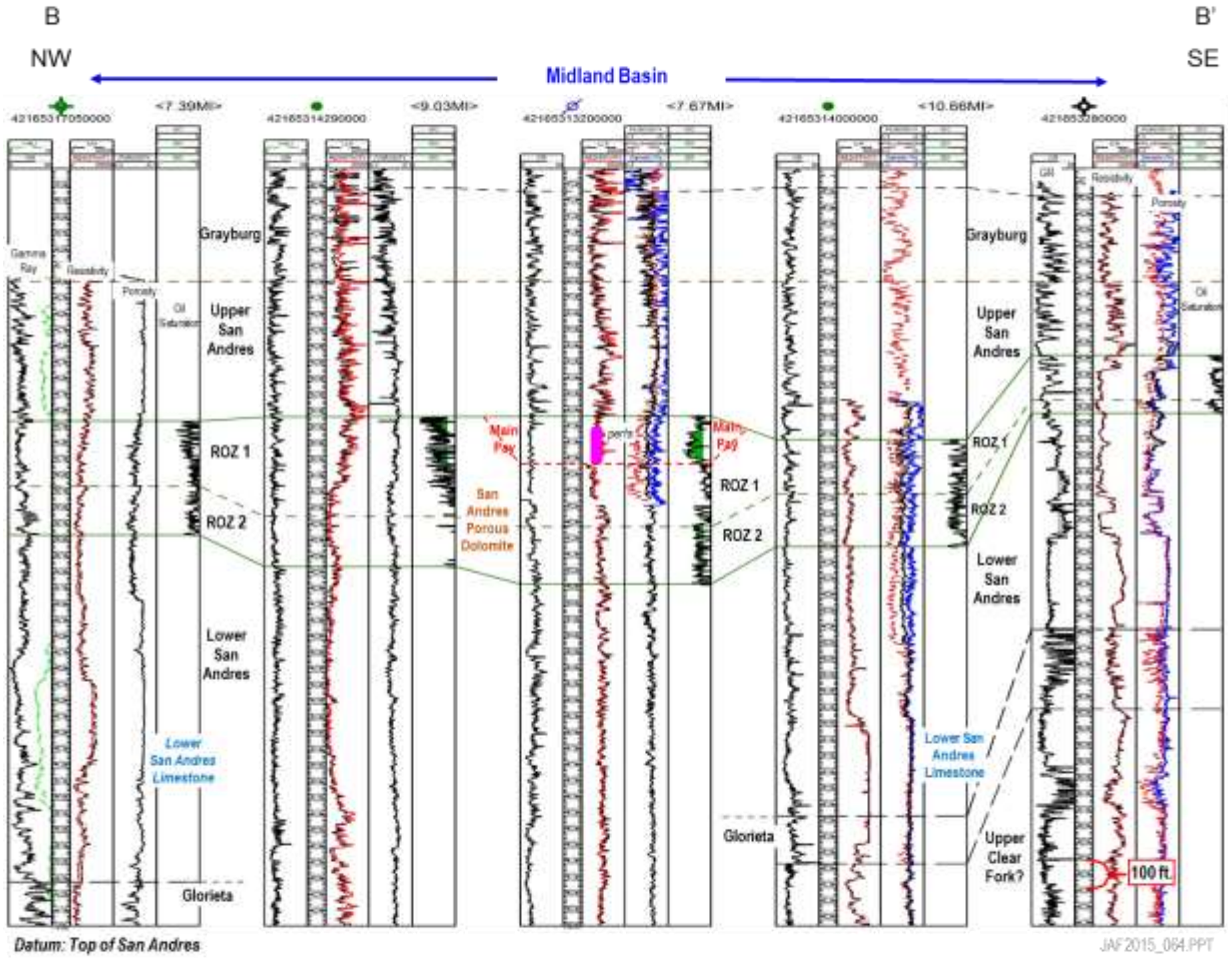
Track 4 on the right shows the calculated oil saturation. Calculated oil saturations between 25 percent and 40 percent are shaded in dark green; calculated oil saturations between 45 percent and 60 percent are shaded in light green; and oil saturation greater than 65 percent, typically present in only the Main Pay Zone, are shaded in black.

Exhibit 7.3A-2 Gaines County NW-SE Cross-Section A-A’



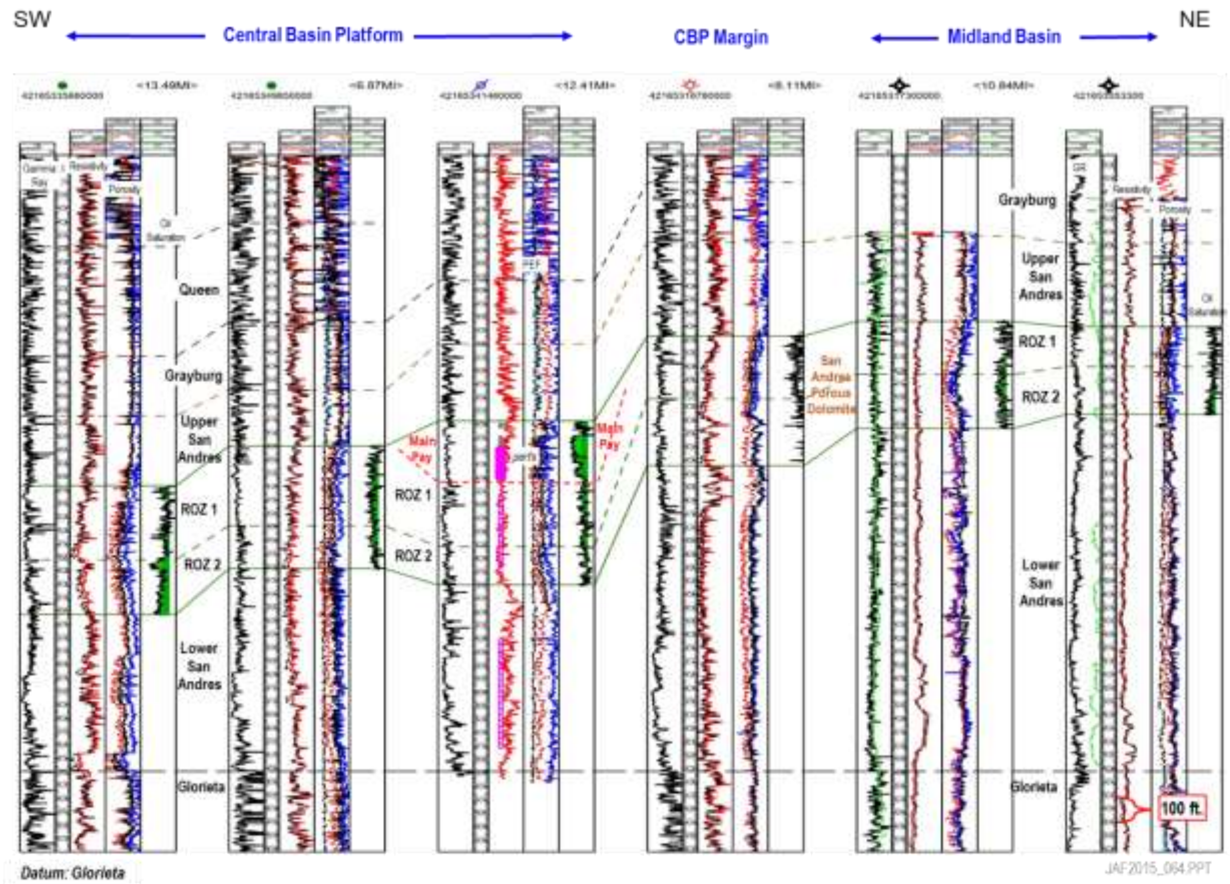
Robin Petrusak rpetrusak@adv-res.com
Vello Kuuskraa vkuuskraa@adv-res.com

Exhibit 7.3A-3 Gaines County NW-SE Cross-Section B-B'



Robin Petrusak rpetrusak@adv-res.com
Vello Kuuskraa vkuuskraa@adv-res.com

Exhibit 7.3A-4 Gaines County SW-NE Cross-Section C-C'



The base of the ROZ is generally picked at the point where either calculated oil saturation or apparent porosity (or both) diminish in the Lower San Andres. If a Lower San Andres limestone or wackestone is prominent, the top of the limestone or wackestone defines the base of the ROZ.

The San Andres ROZ interval and net pay in Gaines County are extensive but vary greatly - - from about 200 to 250 feet on the Northwest Shelf to over 350 feet on the Central Basin Platform in the western portion of the county. Oil saturations and porosity also tend to be relatively favorable in these two areas. Outside the Central Basin Platform, in the eastern half of the county, the net pay of the ROZ interval becomes thinner and tends to have lower oil saturation.

7.3A.4 Gaines County "Type Log"

A "type log" was selected from the Gaines County study wells to illustrate the ROZ resource analysis undertaken for the county. Exhibit 7.3A-5 provides a close-up display of calculated porosity and oil saturation for the ROZ in the "type log." The "type log" illustrates two distinct San Andres ROZ resource intervals - - ROZ "1" in the upper portion of the Lower San Andres porous dolomite, and ROZ "2" in the lower portion of the Lower San Andres porous dolomite. These two intervals are readily distinguished by gamma ray and resistivity log character and by the calculated oil saturation. The ROZ "2" appears to have more shale and thinner individual porous dolomite zones. Thin, tight limestones are also present toward the base of the ROZ "2" interval.

The "type log" shows lithology-corrected neutron (red dash) and density (blue) porosity. The density-neutron cross-plot porosity is shown in black. Porosity is fairly uniform through the ROZ, but calculated oil saturation diminishes significantly at the base of ROZ "1". Exhibit 7.3A-5 illustrates that the base of the ROZ is often not clearly defined. In this well, porosity diminishes below 5,430 feet. From the gamma ray log, more shale appears to be present in the ROZ interval below this depth. The base of the ROZ is picked at the top of a thick low porosity interval that occurs at approximately 5,510 feet. If available, additional data such as core, mud logs, or sample logs would assist on where to pick the base of the ROZ.

The oil saturation for the type log ROZ was calculated using the following Archie parameters - - ‘m’ of 2.3, ‘n’ of 3.0, ‘a’ of 1.0, and formation water resistivity (Rw) of 0.055. A porosity cut-off of 6 percent was applied to define net pay in the ROZ. Intervals identified as ROZ pay are shown by the red “pay” flag in Track 1 of Exhibit 7.3A-5.

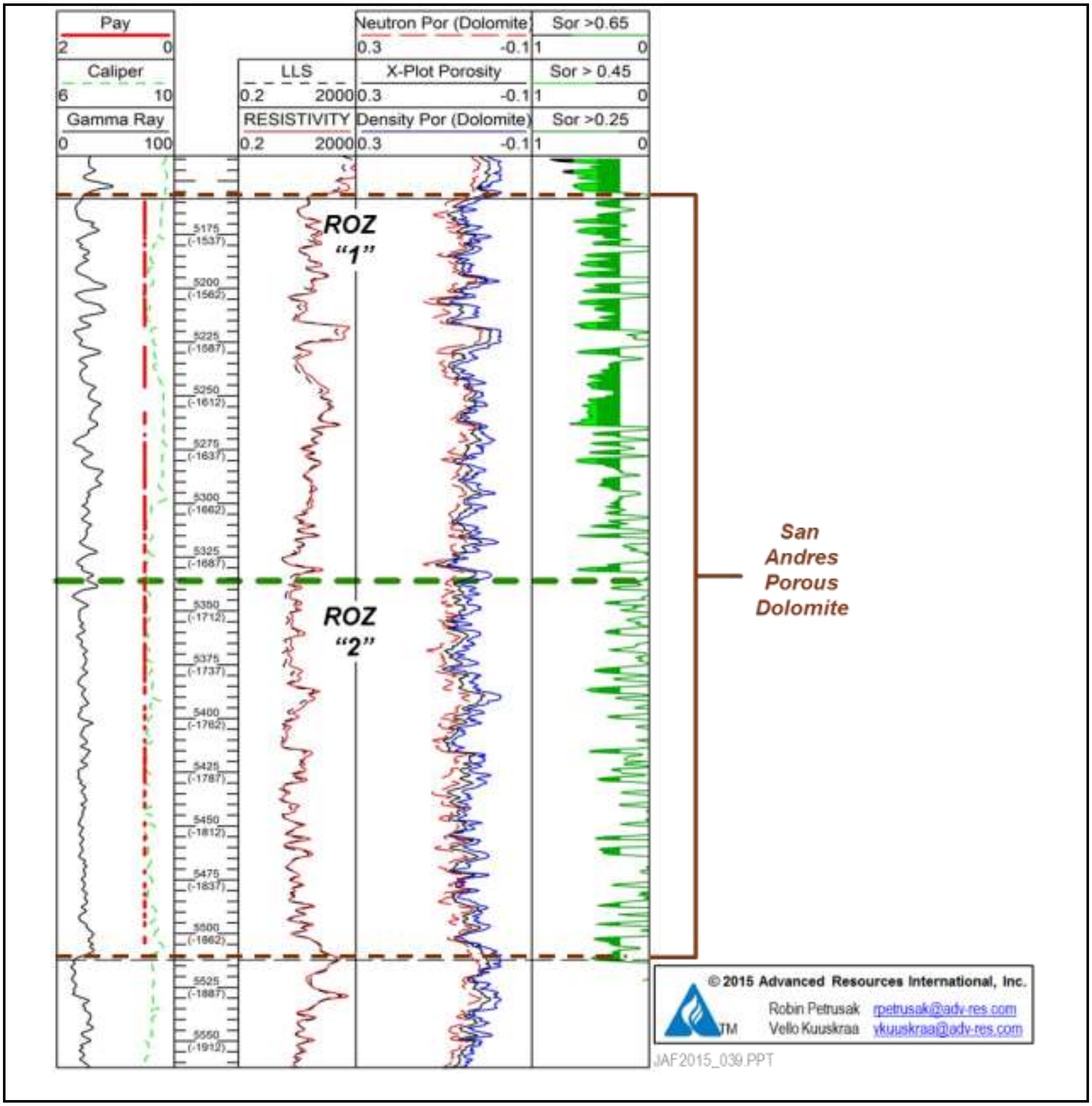
For ROZ “1,” the average porosity of net pay is 8.4 % and average oil saturation of net pay is 36%. Note that the highest calculated oil saturations occur at the top of ROZ “1”. As discussed in Section 2.4.5 of the report, the ROZ “1” resource in the “type log” is characterized as “higher quality”. For ROZ “2”, the average porosity of net pay is 9.1% and average oil saturation is only 18%. Consequently, the ROZ “2” interval in the “type log” is characterized as “lower quality.”

7.3A.5 Partitioning the Gaines County San Andres ROZ “Fairway”

The San Andres ROZ “fairway” in Gaines County is partitioned into five distinct areas, as illustrated in Exhibit 7.3A-1. Individual San Andres ROZ “fairway” resource assessments were undertaken for each of the five partitioned areas. The definition of the partitions was guided by the current structure and prominent features of the Permian Basin within the Gaines County San Andres ROZ “fairway” study area.

- <u>Partition #1</u>. Covers a 34,000 acre (53 mi^2) area of northwest Gaines County on the Northwest Shelf. The southern portion of the Wasson oil field, covering 11,200 acres (18 mi^2), has been excluded from the ROZ “fairway” resource assessment area of Partition #1.
- <u>Partition #2</u>. Covers a 75,000 acre (117 mi^2) area of northwest Gaines County in the San Simon Channel. Three small San Andres oil fields - - Russell, South (1,700 acres), Havemeyer (1,200 acres) and ODC (2,800 acres) - - have been excluded from the ROZ “fairway” resource assessment area for Partition #2.
- <u>Partition #3</u>. Covers a 142,000 acre (222 mi^2) area of western Gaines County on the northern portion of the Central Basin Platform. The Seminole oil field (23,700 acres) and the various Seminole oil field extensions (13,200 acres) have been excluded from the ROZ “fairway” resource assessment area for Partition #3, as have the Blackwatch oil field (2,000 acres) and a portion of the Hanford oil field (2,200 acres). The total area excluded from the ROZ “fairway” resource assessment for Partition #3 is 41,000 acres (64 mi^2).

Exhibit 7.3A-5 Type Log for Gaines County San Andres ROZ "Fairway"



Source: Petrusak, R. and V.A. Kuuskraa, 2014, ROZ Fairway Resources of the Permian Basin: A Four-County Resource Assessment, slide no. 97, presentation prepared for Research Partnership to Secure Energy for America (RPSEA), June 25, 2014

- Partition #4. Covers a 184,000 acre (288 mi^2) area of southern Gaines County. A 15,500 acre (24 mi^2) area, encompassing Robertson, No. Robertson, Jenkins and Carm-Ann oil fields, has been excluded from the ROZ "fairway" resource assessment area for Partition #4.
- Partition #5. Covers a 423,000 acre (661 mi^2) area encompassing the eastern half of Gaines County beyond the current extent of the Central Basin Platform. A total of 30,500 acres (48 mi^2) from five oil fields (Hanford, GMK, Adair/TLOC, Cedar Lake and Homann) has been excluded from the ROZ "fairway" resource assessment area for Partition #5.

Gaines County covers a 961,900 acre area of the Permian Basin. A total of 103,900 acres (162 mi^2) under the structural closure of existing San Andres oil fields has been excluded, leaving a remaining San Andres ROZ "fairway" assessment area of 858,000 acres (1,341 mi^2), Exhibit 7.3A-6.

Exhibit 7.3A-6 Gaines County ROZ "Fairway" Partitions

Partition	Total Area	Excluded Area	Assessment Area
	(Acres)	(Acres)	(Acres)
#1	45,200	11,200	34,000
#2	80,700	5,700	75,000
#3	183,000	41,000	142,000
#4	199,500	15,500	184,000
#5	453,500	30,500	423,000
Total	961,900	103,900	858,000

Source: Advanced Resources International, 2015.

7.3A.6 Size and Quality of the Gaines County ROZ "Fairway" Resource

Gaines County, Texas holds 45.5 billion barrels of oil in-place in the San Andres ROZ "fairway" outside the structural closure of the existing oil fields. The oil in-place and resource quality values provided for each of the five partitions for Gaines County are shown in Exhibit 7.3A-7.

- Higher Quality ROZ "Fairway" Resources. A significant portion of the San Andres ROZ "fairway" oil in-place in Gaines County of 35.4 billion barrels has "higher quality" reservoir properties (porosity greater than 8% and oil saturation equal to or greater than 25%), offering promise for commercial development of the ROZ resource with by-product storage of CO_2.

- Lower Quality ROZ "Fairway" Resources. The remainder of the San Andres ROZ "fairway" oil in-place in Gaines County of 10.1 billion barrels has "lower quality" reservoir properties (porosity equal to or less than 8% and/or oil saturation of less than 25%), offering important volumes of pore space for storage of CO_2 with by-product recovery of oil.

Exhibit 7.3A-7 Gaines County San Andres ROZ "Fairway" Resource In-Place (Billion Barrels)

Partitions	ROZ 1			ROZ 2			Total		
	Higher Quality	Lower Quality	Total	Higher Quality	Lower Quality	Total	Higher Quality	Lower Quality	Total
#1	0.62	0.15	0.77	0.35	0.15	0.50	0.97	0.30	1.27
#2	2.15	0.30	2.45	1.37	0.40	1.77	3.52	0.70	4.22
#3	5.46	0.39	5.85	5.59	0.28	5.87	11.05	0.67	11.72
#4	6.36	0.37	6.73	4.41	1.89	6.30	10.77	2.26	13.03
#5	3.10	3.84	6.94	5.97	2.34	8.31	9.07	6.18	15.25
Total	**17.69**	**5.05**	**22.74**	**17.69**	**5.06**	**22.75**	**35.38**	**10.11**	**45.49**

Source: Advanced Resources International, 2015.

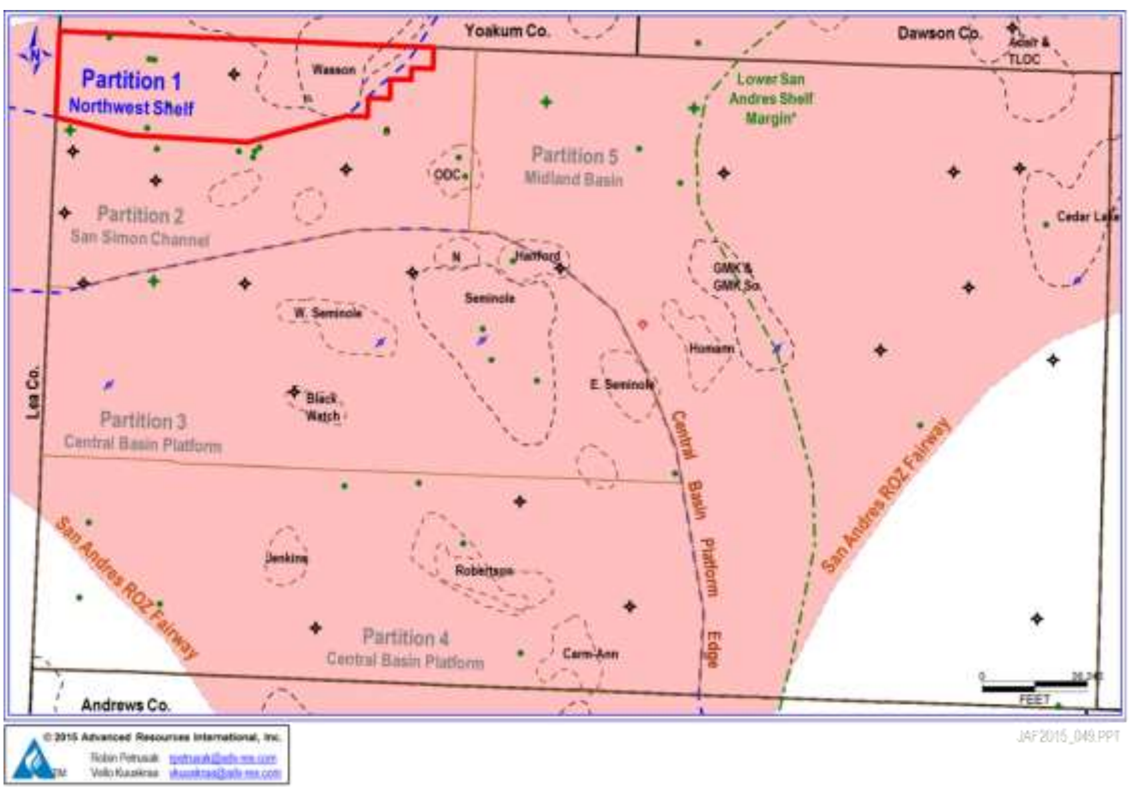
7.3A.7 Partition #1. Northwest Gaines County

Geologic Setting

Partition #1, located in northwestern Gaines County, covers a San Andres ROZ “fairway” area (outside the structural limits of existing oil fields) of 34,000 acres, Exhibit 7.3A-8. The partition area excludes the southern portion of the Wasson oil field (11,200 acres). Partition #1 is located within the previously established San Andres ROZ “fairway” boundaries, on the Northwest Shelf of the Permian Basin.

The San Andres ROZ “fairway” reservoir interval in Partition #1 of Gaines County has a net thickness that ranges generally from 100 to 370 feet, within a gross interval of 310 to 400 feet (including ROZ 1 and ROZ 2). However, one study well in Partition #1 has very limited San Andres ROZ Net Pay. The ROZ interval has a porosity of 7% to 10% and holds an oil saturation that ranges from below 20% to above 40%. Oil saturation for the study wells in Partition 1 was calculated using Archie parameters: ‘m’ = 2.3; ‘n’ = 2.3; ‘a’ = 1; Rw = 0.055 ohm-m.

Exhibit 7.3A-8 San Andres ROZ “Fairway” Partition #1, Gaines County



Source: Advanced Resources International and Melzer Consulting, 2015.

7.3A.8 Analytical ROZ Reservoir Units

A series of six well log-based reservoir data sets plus a series of working level cross-sections were used to further divide the San Andres ROZ "fairway" resource in Partition #1 of Gaines County into four analytical ROZ "fairway" reservoir units, as set forth below:

- A "higher quality" (HQ) ROZ #1 (Upper ROZ) interval
- A "lower quality" (LQ) ROZ #1 (Upper ROZ) interval
- A "higher quality" (HQ) ROZ #2 (Lower ROZ) interval
- A "lower quality" (LQ) ROZ #2 (Lower ROZ) interval

A "higher quality" analytical ROZ "fairway" reservoir unit has an average porosity greater than 8% and an average oil saturation greater than 25% for its net pay. A "lower quality" analytical ROZ "fairway" reservoir unit has an average porosity less than 8% and/or an average oil saturation less than 25% for its net pay.

A major purpose of the separation of the ROZ "fairway" resource into quality-based analytical reservoir units is to help establish the geological settings where: (1) the ROZ interval may have potential for commercial oil recovery with by-product storage of CO_2, and (2) where the ROZ interval may serve primarily as a location for storage of CO_2 with by-product production of oil.

The average volumetric reservoir properties for the four analytical San Andres ROZ "fairway" reservoir units of Partition #1 of Gaines County are provided in Exhibit 7.3A-9.

7.3A.9 ROZ Oil In-Place

The San Andres ROZ "fairway" in Partition #1 of Gaines County contains 1.27 billion barrels of oil in-place, Exhibit 7.3A-10. The bulk of the ROZ oil in-place (0.97 billion barrels) meets the "higher" ROZ resource quality criteria, offering the potential for commercial oil recovery with by-product storage of CO_2. The remainder of the ROZ oil in-place of 0.30 billion barrels meets the "lower" resource quality criteria, offering pore space for the storage of CO_2 with by-product production of oil.

Exhibit 7.3A-9 Average San Andres ROZ "Fairway" Reservoir Properties: Partition #1, Gaines County

	ROZ 1		ROZ 2	
	Higher Quality	**Lower Quality**	**Higher Quality**	**Lower Quality**
Gross Thickness (ft)	210	138	144	188
Net Pay (ft)	169	60	118	65
Avg. Porosity (fraction)	0.089	0.076	0.096	0.077
Avg. Oil Saturation (fraction)	0.40	0.31	0.46	0.22
Avg. Formation Volume Factor	1.28	1.28	1.28	1.28
OIP (B/AF, for net pay)	216	143	268	103

Source: Advanced Resources International, 2015.

Exhibit 7.3A-10 San Andres ROZ "Fairway" Oil In-Place: Partition #1, Gaines County

	ROZ 1		ROZ 2	
	Higher Quality	**Lower Quality**	**Higher Quality**	**Lower Quality**
Oil In-Place (B/Acre)	36,500	8,580	31,620	6,700
Area Extent (Acres)	17,000	17,000	11,000	23,000
Oil In-Place (Billion Barrels)	0.62	0.15	0.35	0.15

Source: Advanced Resources International, 2015.

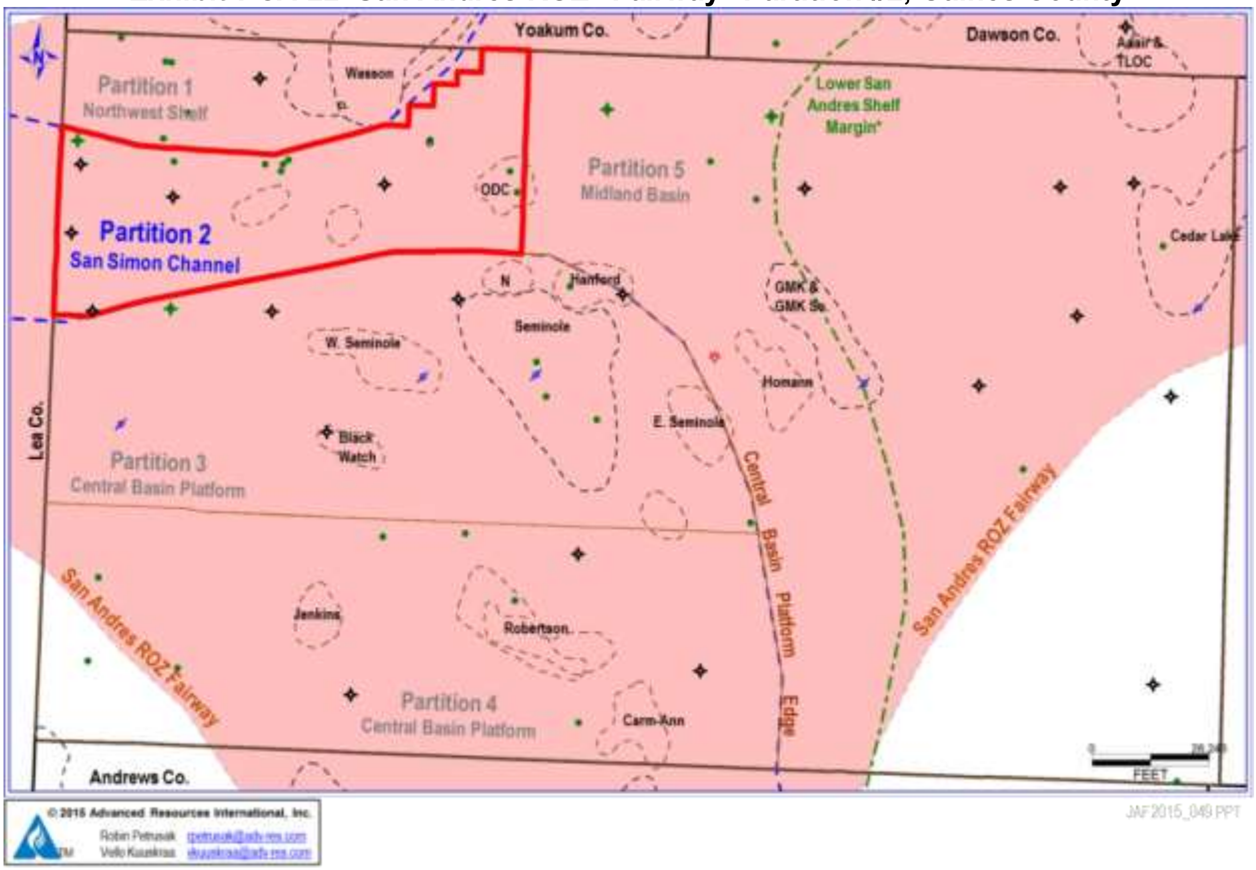
7.3A.10 Partition #2. Northwest Gaines County – San Simon Channel

Geologic Setting

Partition #2, located in northwest Gaines County, covers a San Andres ROZ "fairway" area (outside the structural limits of existing oil fields) of 75,000 acres, Exhibit 7.3A-11. The partition area excludes the Russell South, Havemeyer and ODC oil fields (5,700 acres). Partition #2 is located within the previously established San Andres ROZ "fairway" boundaries, in the San

Simon Channel of the Permian Basin between the Northwest Shelf and the Central Basin Platform.

Exhibit 7.3A-11 San Andres ROZ "Fairway" Partition #2, Gaines County



Source: Advanced Resources International and Melzer Consulting, 2015.

The San Andres ROZ "fairway" reservoir interval in Partition #2 of Gaines County has a net thickness that ranges from 100 to 360 feet, within a gross interval of 200 to 430 feet (including ROZ 1 and ROZ 2). The ROZ interval has a porosity of 7% to 10% and holds a relatively high residual oil saturation that ranges from 20% to well above 40%. Oil saturation for the study wells in Partition 2 was calculated using Archie parameters: 'm' = 2.3 to 2.5; 'n' = 3; 'a' = 1; Rw = 0.055 ohm-m.

7.3A.11 Analytical ROZ Reservoir Units

A series of eight well log-based reservoir data sets plus a series of working level cross-sections were used to further divide the San Andres ROZ "fairway" resource in Partition #2 of Gaines County into four analytical ROZ "fairway" reservoir units, as set forth below:

- A "higher quality" (HQ) ROZ #1 (Upper ROZ) interval
- A "lower quality" (LQ) ROZ #1 (Upper ROZ) interval
- A "higher quality" (HQ) ROZ #2 (Lower ROZ) interval
- A "lower quality" (LQ) ROZ #2 (Lower ROZ) interval

A "higher quality" analytical ROZ "fairway" reservoir unit has an average porosity greater than 8% and an average oil saturation greater than 25% for its net pay. A "lower quality" analytical ROZ "fairway" reservoir unit has an average porosity less than 8% and/or an average oil saturation less than 25% for its net pay.

A major purpose of the separation of the ROZ "fairway" resource into quality-based analytical reservoir units is to help establish the geological settings where: (1) the ROZ interval may have potential for commercial oil recovery with by-product storage of CO_2, and (2) where the ROZ interval may serve primarily as a location for storage of CO_2 with by-product production of oil.

The average volumetric reservoir properties for the four analytical San Andres ROZ "fairway" reservoir units of Partition #2 of Gaines County are provided in Exhibit 7.3A-12.

Exhibit 7.3A-12 Average San Andres ROZ "Fairway" Reservoir Properties: Partition #2, Gaines County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Gross Thickness (ft)	186	151	155	138
Net Pay (ft)	159	92	134	109
Avg. Porosity (fraction)	0.090	0.080	0.090	0.087
Avg. Oil Saturation (fraction)	0.44	0.36	0.40	0.25
Avg. Formation Volume Factor	1.28	1.28	1.28	1.28
OIP (B/AF, for net pay)	240	175	218	132

Source: Advanced Resources International, 2015

7.3A.12 ROZ Oil In-Place

The San Andres ROZ "fairway" in Partition #2 of Gaines County contains 4.23 billion barrels of oil in-place, Exhibit 7.3A-13. The bulk of the ROZ oil in-place (3.52 billion barrels) meets the "higher" ROZ resource quality criteria, offering the potential for commercial oil recovery with by-product storage of CO_2. The remainder of the ROZ oil in-place of 0.71 billion barrels meets the "lower" resource quality criteria, offering pore space for the storage of CO_2 with by-product production of oil.

Exhibit 7.3A-13 San Andres ROZ "Fairway" Oil In-Place: Partition #2, Gaines County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Oil In-Place (B/Acre)	38,160	16,100	29,210	14,390
Area Extent (Acres)	56,250	18,750	47,000	28,000
Oil In-Place (Billion Barrels)	2.15	0.31	1.37	0.40

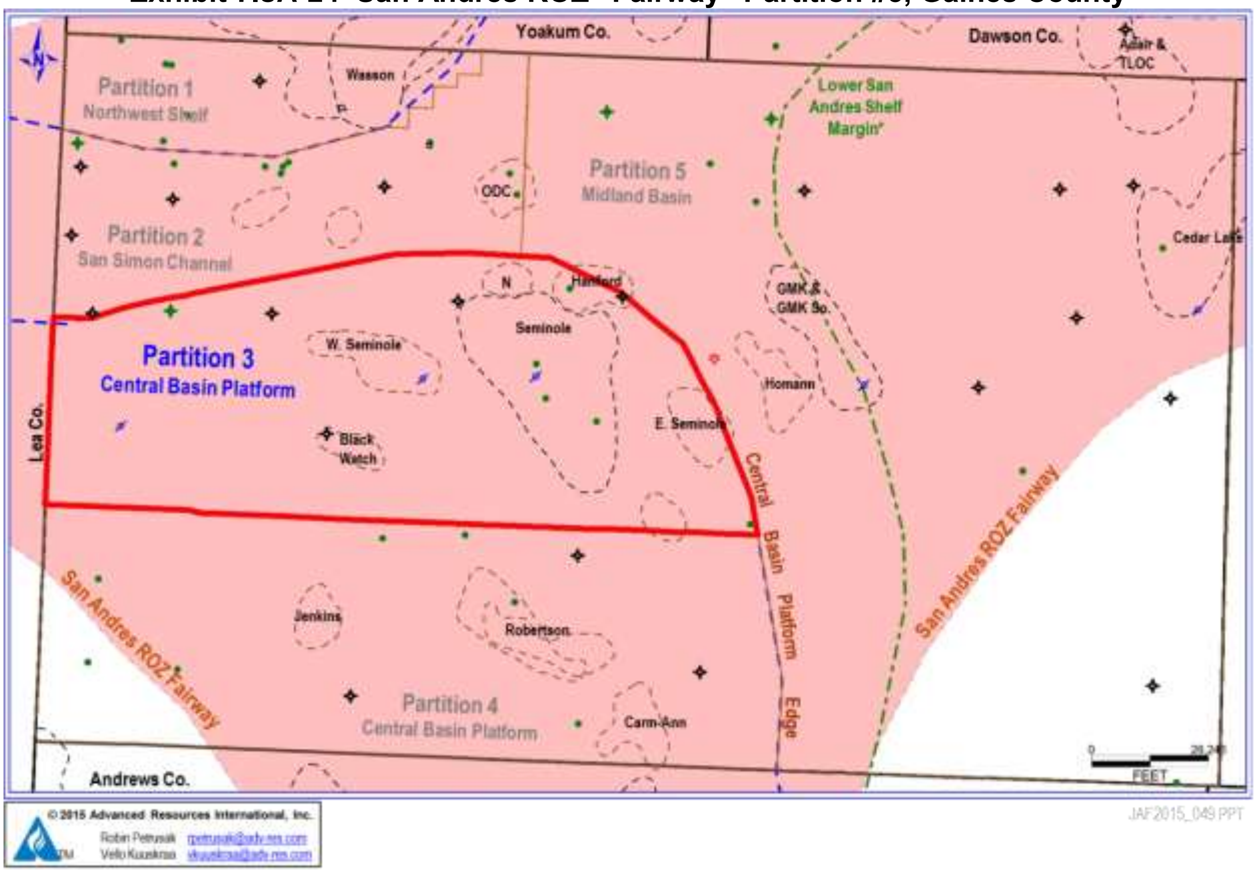
Source: Advanced Resources International, 2015.

7.3A.13 Partition #3. West Central Gaines County

Geologic Setting

Partition #3, located in west-central Gaines County, covers a San Andres ROZ "fairway" area (outside the structural limits of existing oil fields) of 142,000 acres, Exhibit 7.3A-14. The partition area excludes several large oil fields such as Seminole, Hanford and Blackwatch (41,000 acres). Partition #3 is located within the previously established San Andres ROZ "fairway" boundaries, on the Central Basin Platform of the Permian Basin.

Exhibit 7.3A-14 San Andres ROZ "Fairway" Partition #3, Gaines County



Source: Advanced Resources International and Melzer Consulting, 2015.

The San Andres ROZ "fairway" reservoir interval in Partition #3 of Gaines County has a net thickness that ranges from 310 to 540 feet, within a gross interval of 410 to 590 feet (including ROZ 1 and ROZ 2). The ROZ interval has a porosity of 8% to 11% and holds an oil saturation that ranges from below 20% to above 40%. Oil saturation for the study wells in Partition 3 was calculated using Archie parameters: 'm' = 2.3; 'n' = 3.4; 'a' = 1; Rw = 0.07 ohm-m.

7.3A.14 Analytical ROZ Reservoir Units

A series of six well log-based reservoir data sets plus a series of working level cross-sections were used to further divide the San Andres ROZ "fairway" resource in Partition #3 of Gaines County into four analytical ROZ "fairway" reservoir units, as set forth below:

- A "higher quality" (HQ) ROZ #1 (Upper ROZ) interval
- A "lower quality" (LQ) ROZ #1 (Upper ROZ) interval
- A "higher quality" (HQ) ROZ #2 (Lower ROZ) interval
- A "lower quality" (LQ) ROZ #2 (Lower ROZ) interval

A "higher quality" analytical ROZ "fairway" reservoir unit has an average porosity greater than 8% and an average oil saturation greater than 25% for its net pay. A "lower quality" analytical ROZ "fairway" reservoir unit has an average porosity less than 8% and/or an average oil saturation less than 25% for its net pay.

A major purpose of the separation of the ROZ "fairway" resource into quality-based analytical reservoir units is to help establish the geological settings where: (1) the ROZ interval may have potential for commercial oil recovery with by-product storage of CO_2, and (2) where the ROZ interval may serve primarily as a location for storage of CO_2 with by-product production of oil.

The average volumetric reservoir properties for the four analytical San Andres ROZ "fairway" reservoir units of Partition #3 of Gaines County are provided on Exhibit 7.3A-15.

Exhibit 7.3A-15 Average San Andres ROZ "Fairway" Reservoir Properties: Partition #3, Gaines County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Gross Thickness (ft)	244	235	248	215
Net Pay (ft)	208	172	224	164
Avg. Porosity (fraction)	0.102	0.092	0.097	0.077
Avg. Oil Saturation (fraction)	0.36	0.17	0.36	0.15
Avg. Formation Volume Factor	1.28	1.28	1.28	1.28
OIP (B/AF, for net pay)	223	95	212	70

Source: Advanced Resources International, 2015.

7.3A.15 ROZ Oil In-Place

The San Andres ROZ "fairway" in Partition #3 of Gaines County contains 11.72 billion barrels of oil in-place, Exhibit 7.3A-16. The bulk of the ROZ oil in-place (11.05 billion barrels) meets the "higher" ROZ resource quality criteria, offering the potential for commercial oil recovery with by-product storage of CO_2. The remainder of the ROZ oil in-place of 0.67 billion barrels meets the "lower" resource quality criteria, offering pore space for the storage of CO_2 with by-product production of oil.

Exhibit 7.3A-16 San Andres ROZ "Fairway" Oil In-Place: Partition #3, Gaines County

	ROZ 1		ROZ 2	
	Higher Quality	**Lower Quality**	**Higher Quality**	**Lower Quality**
Oil In-Place (B/Acre)	46,380	16,340	47,490	11,480
Area Extent (Acres)	118,000	24,000	118,000	24,000
Oil In-Place (Billion Barrels)	5.46	0.39	5.59	0.28

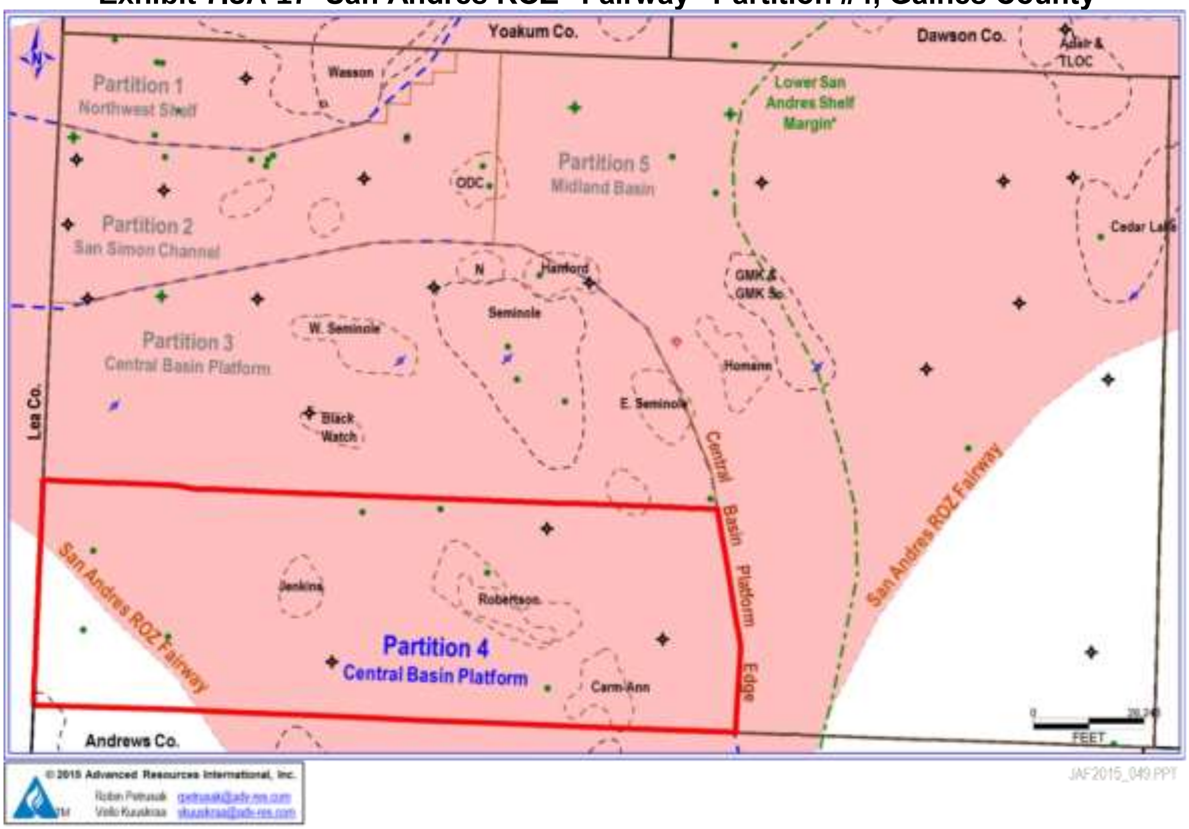
Source: Advanced Resources International, 2014

7.3A.16 Partition #4. Southern Gaines County – Central Basin Platform

Geologic Setting

Partition #4, located in southern Gaines County, covers a San Andres ROZ "fairway" area (outside the structural limits of existing oil fields) of 184,000 acres, Exhibit 7.3A-17 The partition area excludes the Robertson, N. Robertson, Jenkins and Carm-Ann oil fields (15,500 acres). Partition #4 is located within the previously established San Andres ROZ "fairway" boundaries, except in the extreme southwest corner of the county on the Central Basin Platform of the Permian Basin.

Exhibit 7.3A-17 San Andres ROZ "Fairway" Partition #4, Gaines County



Source: Advanced Resources International and Melzer Consulting, 2015.

The San Andres ROZ "fairway" reservoir interval in Partition #4 of Gaines County has a net thickness that ranges from 250 to 380 feet, within a gross interval of 410 to 460 feet (including ROZ 1 and ROZ 2). The ROZ interval has a porosity of 7% to 12% and holds an oil saturation that ranges from below 15% to above 40%. Oil saturation for the study wells in Partition 4 was calculated using Archie parameters: 'm' = 2.3; 'n' = 3.4; 'a' = 1; Rw = 0.07 ohm-m.

7.3A.17 Analytical ROZ Reservoir Units

A series of eight well log-based reservoir data sets plus a series of working level cross-sections were used to further divide the San Andres ROZ "fairway" resource in Partition #4 of Gaines County into four analytical ROZ "fairway" reservoir units, as set forth below:

- A "higher quality" (HQ) ROZ #1 (Upper ROZ) interval
- A "lower quality" (LQ) ROZ #1 (Upper ROZ) interval
- A "higher quality" (HQ) ROZ #2 (Lower ROZ) interval
- A "lower quality" (LQ) ROZ #2 (Lower ROZ) interval

A "higher quality" analytical ROZ "fairway" reservoir unit has an average porosity greater than 8% and an average oil saturation greater than 25% for its net pay. A "lower quality" analytical ROZ "fairway" reservoir unit has an average porosity less than 8% and/or an average oil saturation less than 25% for its net pay.

A major purpose of the separation of the ROZ "fairway" resource into quality-based analytical reservoir units is to help establish the geological settings where: (1) the ROZ interval may have potential for commercial oil recovery with by-product storage of CO_2, and (2) where the ROZ interval may serve primarily as a location for storage of CO_2 with by-product production of oil.

The average volumetric reservoir properties for the four analytical San Andres ROZ "fairway" reservoir units of Partition #4 of Gaines County are provided on Exhibit 7.3A-18.

Exhibit 7.3A-18 Average San Andres ROZ "Fairway" Reservoir Properties: Partition #4, Gaines County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Gross Thickness (ft)	224	192	198	218
Net Pay (ft)	200	101	168	157
Avg. Porosity (fraction)	0.106	0.086	0.107	0.096
Avg. Oil Saturation (fraction)	0.35	0.15	0.43	0.22
Avg. Formation Volume Factor	1.25	1.25	1.25	1.25
OIP (B/AF, for net pay)	230	80	286	131

Source: Advanced Resources International, 2015.

7.3A.18 ROZ Oil In-Place

The San Andres ROZ "fairway" in Partition #4 of Gaines County contains 13.03 billion barrels of oil in-place, Exhibit 7.3A-19. The bulk of the ROZ oil in-place (10.77 billion barrels) meets the "higher" ROZ resource quality criteria, thus offering the potential for commercial oil recovery with by-product storage of CO_2. The remainder of the ROZ oil in-place of 2.26 billion barrels meets the "lower" resource quality criteria, thus offering pore space for the storage of CO_2 with by-product production of oil.

Exhibit 7.3A-19 San Andres ROZ "Fairway" Oil In-Place: Partition #4, Gaines County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Oil In-Place (B/Acre)	46,000	8,080	48,050	20,570
Area Extent (Acres)	138,000	46,000	92,000	92,000
Oil In-Place (Billion Barrels)	6.36	0.37	4.41	1.89

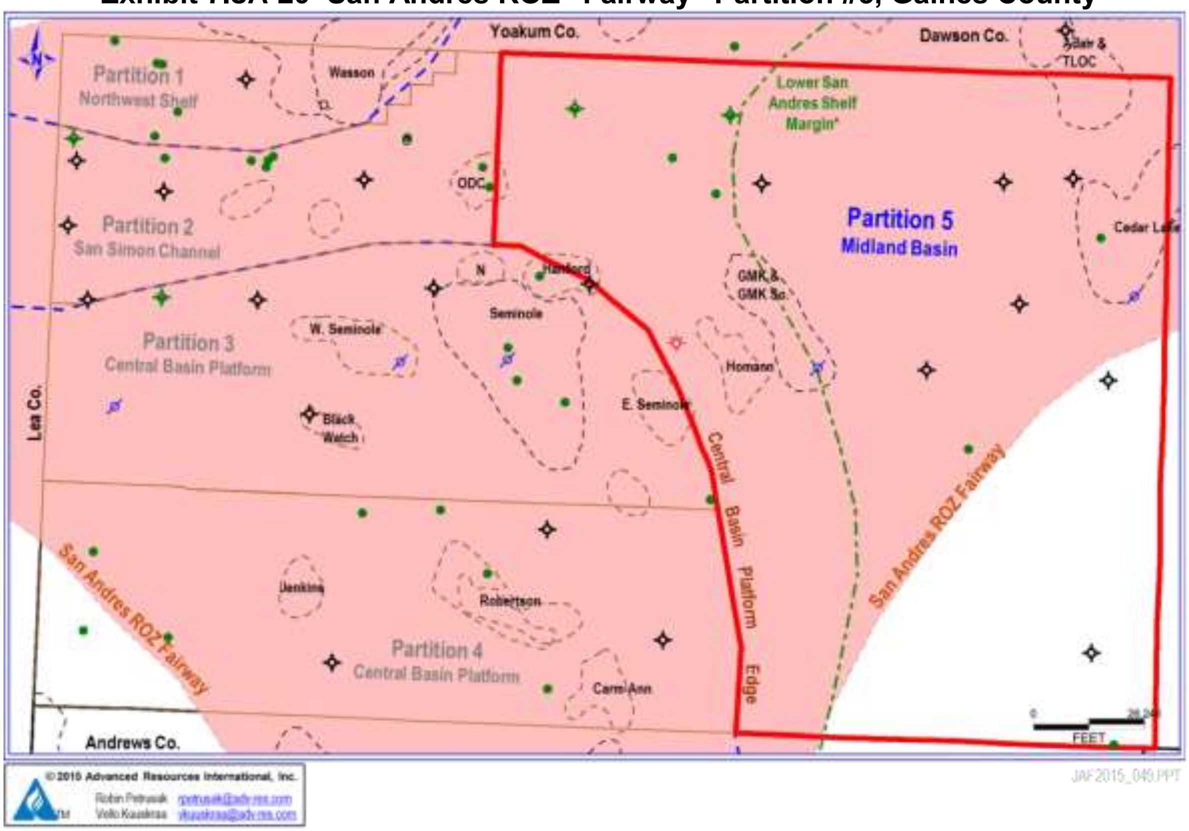
Source: Advanced Resources International, 2015

7.3A.19 Partition #5. Eastern Gaines County

Geologic Setting

Partition #5, located in eastern half of Gaines County, covers a San Andres ROZ "fairway" area (outside the structural limits of existing oil fields) of 423,000 acres, Exhibit 7.3A-20. The partition area excludes portions of the Adair/TLOC, Cedar Lake and Hanford oil fields as well as the Homann and GMK oil fields (30,500 acres). Partition #5 is located within the previously established San Andres ROZ "fairway" boundaries (except for the southeast corner of the county), in the Midland Basin portion of the Permian Basin.

Exhibit 7.3A-20 San Andres ROZ "Fairway" Partition #5, Gaines County



Source: Advanced Resources International and Melzer Consulting, 2015.

The San Andres ROZ "fairway" reservoir interval in Partition #5 of Gaines County has a net thickness that ranges from 60 to 350 feet, within a gross interval of 140 to 400 feet (including ROZ 1 and ROZ 2). The ROZ interval has a porosity of 10% to 14% and holds an oil saturation that ranges from below 15% to above 30%. Oil saturation for the study wells in Partition 5 was calculated using Archie parameters: ‘m’ = 2.3; ‘n’ = 2.3; ‘a’ = 1; Rw = 0.055 ohm-m.

7.3A.20 Analytical ROZ Reservoir Units

A series of eleven well log-based reservoir data sets plus a series of working level cross-sections were used to further divide the San Andres ROZ “fairway” resource in Partition #5 of Gaines County into four analytical ROZ “fairway” reservoir units, as set forth below:

- A “higher quality” (HQ) ROZ #1 (Upper ROZ) interval
- A “lower quality” (LQ) ROZ #1 (Upper ROZ) interval
- A “higher quality” (HQ) ROZ #2 (Lower ROZ) interval
- A “lower quality” (LQ) ROZ #2 (Lower ROZ) interval

A “higher quality” analytical ROZ “fairway” reservoir unit has an average porosity greater than 8% and an average oil saturation greater than 25% for its net pay. A “lower quality” analytical ROZ “fairway” reservoir unit has an average porosity less than 8% and/or an average oil saturation less than 25% for its net pay.

A major purpose of the separation of the ROZ “fairway” resource into quality-based analytical reservoir units is to help establish the geological settings where: (1) the ROZ interval may have potential for commercial oil recovery with by-product storage of CO_2, and (2) where the ROZ interval may serve primarily as a location for storage of CO_2 with by-product production of oil.

The average volumetric reservoir properties for the four analytical San Andres ROZ “fairway” reservoir units of Partition #5 of Gaines County are provided on Exhibit 7.3A-21.

Exhibit 7.3A-21 Average San Andres ROZ “Fairway” Reservoir Properties: Partition #5 Gaines County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Gross Thickness (ft)	174	168	183	148
Net Pay (ft)	136	108	176	79
Avg. Porosity (fraction)	0.109	0.112	0.118	0.113
Avg. Oil Saturation (fraction)	0.30	0.17	0.31	0.16
Avg. Formation Volume Factor	1.28	1.28	1.28	1.28
OIP (B/AF, for net pay)	198	115	222	110

Source: Advanced Resources International, 2015

7.3A.21 ROZ Oil In-Place

The San Andres ROZ "fairway" in Partition #5 of Gaines County contains 15.25 billion barrels of oil in-place, Exhibit 7.3A-22. The bulk of the ROZ oil in-place (9.07 billion barrels) meets the "higher" ROZ resource quality criteria, thus offering the potential for commercial oil recovery with by-product storage of CO_2. The remainder of the ROZ oil in-place of 6.18 billion barrels meets the "lower" resource quality criteria, thus offering pore space for the storage of CO_2 with by-product production of oil.

Exhibit 7.3A-22 San Andres ROZ "Fairway" Oil In-Place: Partition #5, Gaines County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Oil In-Place (B/Acre)	26,930	12,420	39,070	8,690
Area Extent (Acres)	115,000	308,000	153,000	270,000
Oil In-Place (Billion Barrels)	3.10	3.84	5.97	2.34

Source: Advanced Resources International, 2015

7.3B Yoakum County

7.3B.1 Geographic and Geologic Setting

Yoakum County, Texas covers a 512,400 acre (801 mi^2) area in the western part of the West Texas portion of the Permian Basin, primarily on the Northwest Shelf.

The county contains numerous major San Andres Formation oil fields, including Wasson, Brahaney, Prentice, Reeves and Ownby, among others. The ROZ resource below these and other existing San Andres oil fields has been excluded from the resource assessment of the San Andres ROZ "fairway" in Yoakum County.

Based on the currently mapped boundary of the San Andres ROZ "fairway", most of Yoakum County, with the exception of the small southwestern corner and the southeastern edge of the county, resides within the previously established ROZ "fairway" boundary.

The Yoakum County map, Exhibit 7.3B-1, shows: (1) the location of 28 study wells; (2) the four ROZ "fairway" partitions; (3) the boundaries of the previously established ROZ "fairway"; (4) the outline of the NW Shelf of the Permian Basin; and (5) the location of three stratigraphic cross-sections featuring the San Andres ROZ. The map also shows the locations of the major San Andres oil fields that have been excluded from the San Andres ROZ "fairway" resource assessment in Yoakum County.

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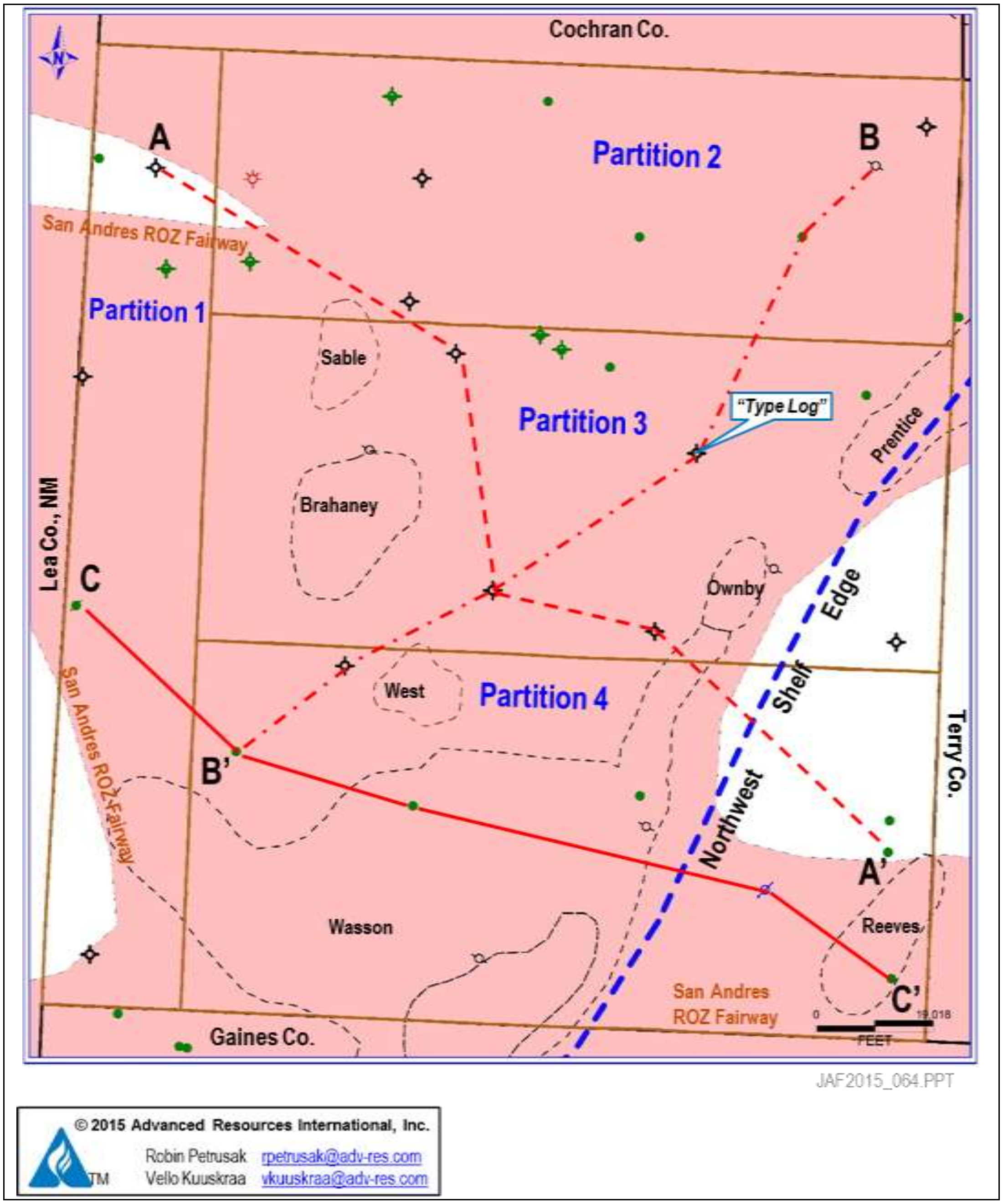
Exhibit 7.3B-1 Yoakum County San Andres ROZ "Fairway": Geologic Partitions, Major Oil Fields and Study Well Locations



Source: Advanced Resources International, 2015.

7.3B.2 Example Yoakum County Cross-Sections

The delineation and characterization of the San Andres ROZ “fairway” interval in Yoakum County has drawn on the construction of a series of working cross-sections. Three of these cross-sections are included in this report.

- Yoakum Co. Cross-Section A-A’ (Exhibit 7.3B-2) provides a NW-SE view of the San Andres ROZ interval starting on the Northwest Shelf in the northwest corner of the county, traversing through the middle of the county, and ending in the Midland Basin in the southeast corner of the county.
- Yoakum Co. Cross-Section B-B’ (Exhibit 7.3B-3) provides a SW-NE view of the San Andres ROZ interval on the Northwest Shelf, starting near the northwest boundary of Wasson Field, traversing through the middle of the county, and ending in the northeast corner of the county.
- Yoakum Co. Cross-Section C-C’ (Exhibit 7.3B-4) provides another NW-SE view of the of the San Andres ROZ interval in the southern part of the county, starting on the west boundary of the county, traversing through a portion of the Wasson oil field, and ending in the Midland Basin at the edge of the Reeves oil field.

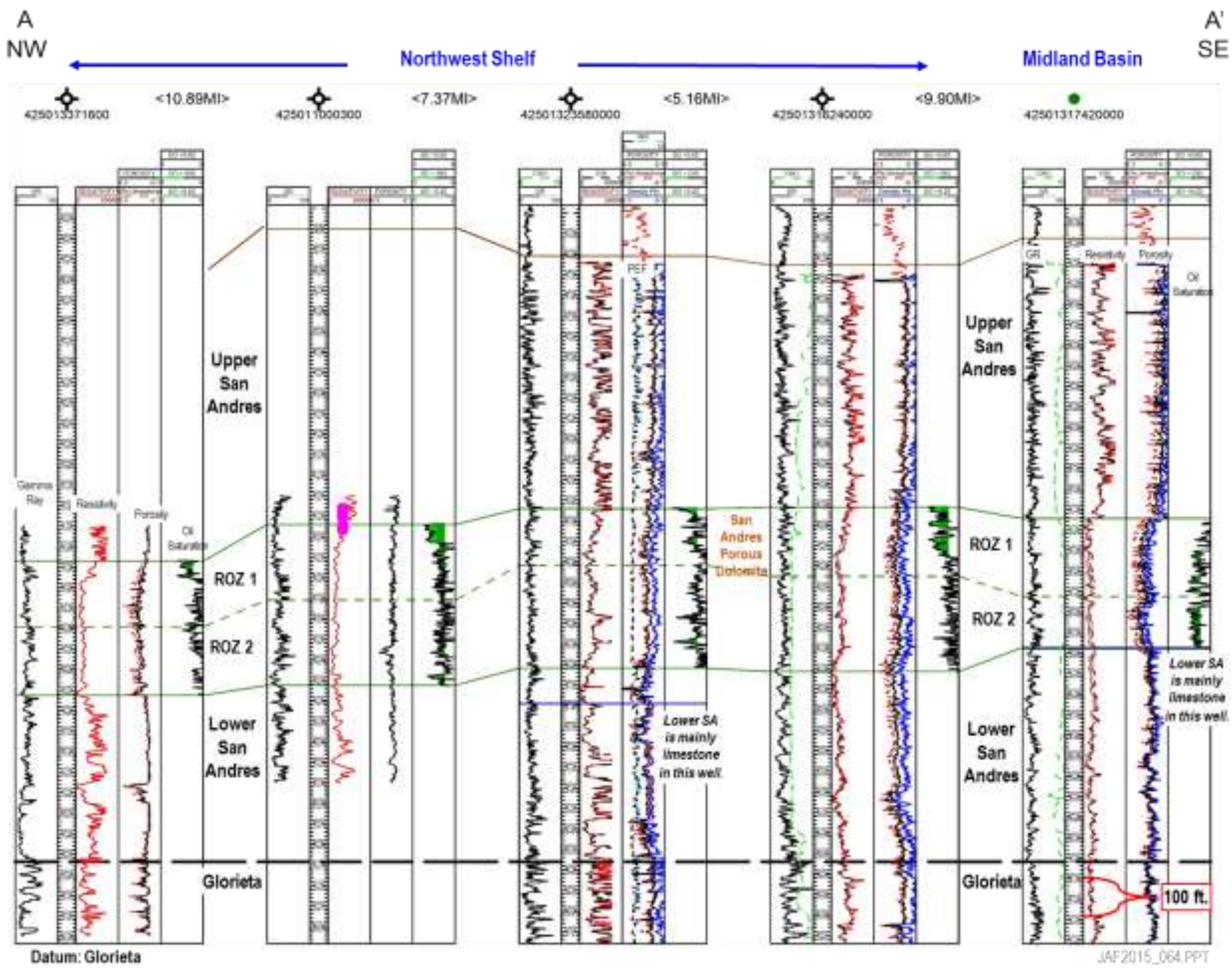
7.3B.3 Interpretation of Yoakum County Cross-Sections

For logs from existing oil fields with a Main Pay Zone, the top of the porous dolomite provides a marker for the top of the Main Pay Zone. For logs from the ROZ “fairway”, the top of the San Andres porous dolomite is picked as the top of the ROZ for this resource assessment. The porous dolomite intervals informally designated as ROZ “1” and ROZ “2” are illustrated on the cross-sections.

The cross-sections display gamma-ray and caliper logs in Track 1 on the left. Resistivity logs are shown in Track 2, with the deep resistivity log shown in red. Track 3 shows the porosity logs. Uncorrected neutron porosity (for limestone) is shown in red; uncorrected density porosity (for limestone) is shown in blue. The porosity curve used for the oil in-place calculation is shown in black. This porosity curve represents the “best available” porosity log for the ROZ, which may be a lithology-corrected neutron-density cross-plot porosity log, a lithology-corrected sonic porosity log, or a corrected neutron or density porosity log.

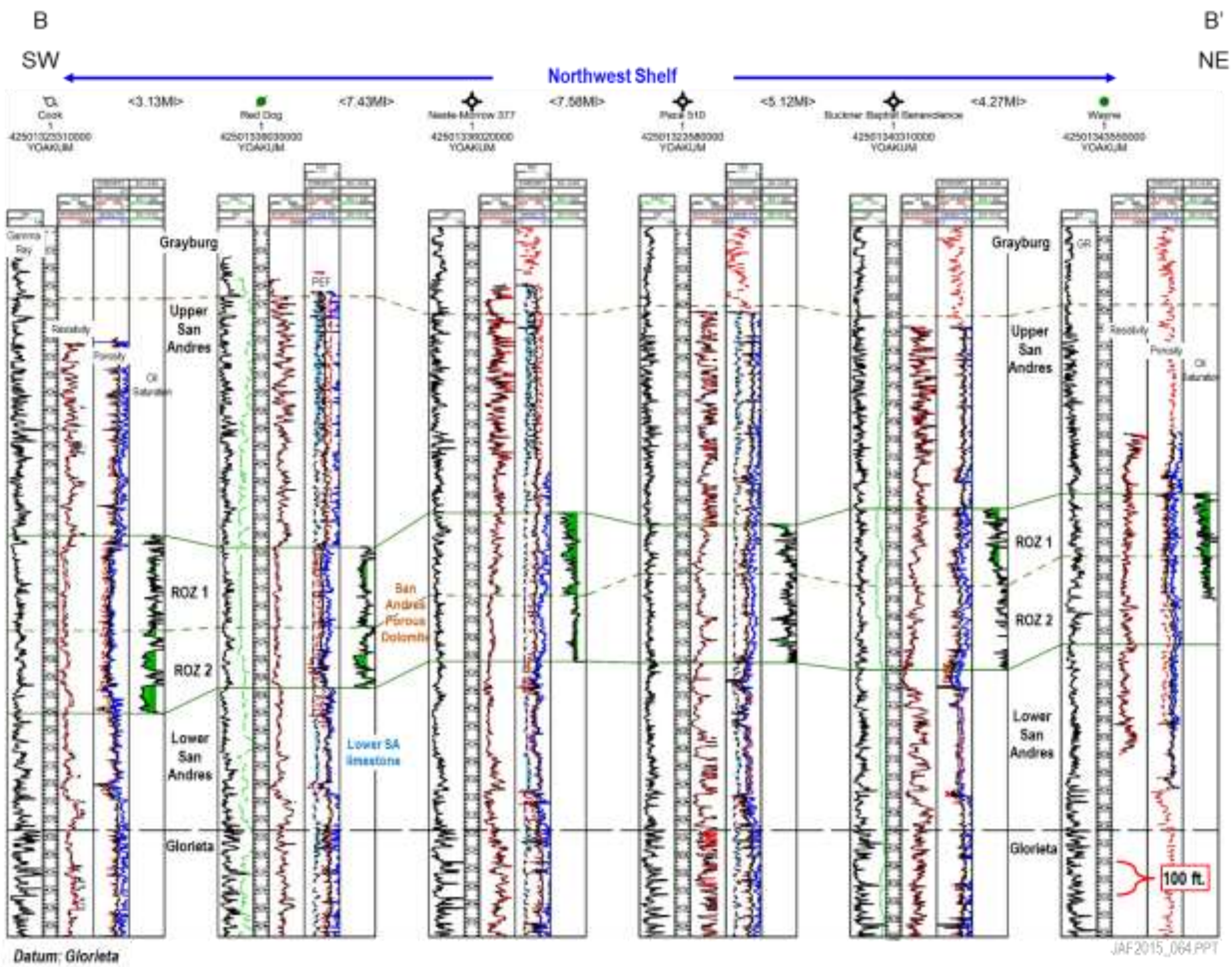
The photo-electric (PEF) curve, if available, is also displayed in Track 3. PEF values greater than “4” are shaded in blue. In the San Andres dolomite above the ROZ, high PEF values greater than “4” likely correspond to anhydrite. Within and below the ROZ interval, high PEF values generally indicate the presence of limestone or dolomitic limestone.

Exhibit 7.3B-2 Yoakum County NW-SE Cross-Section A-A'



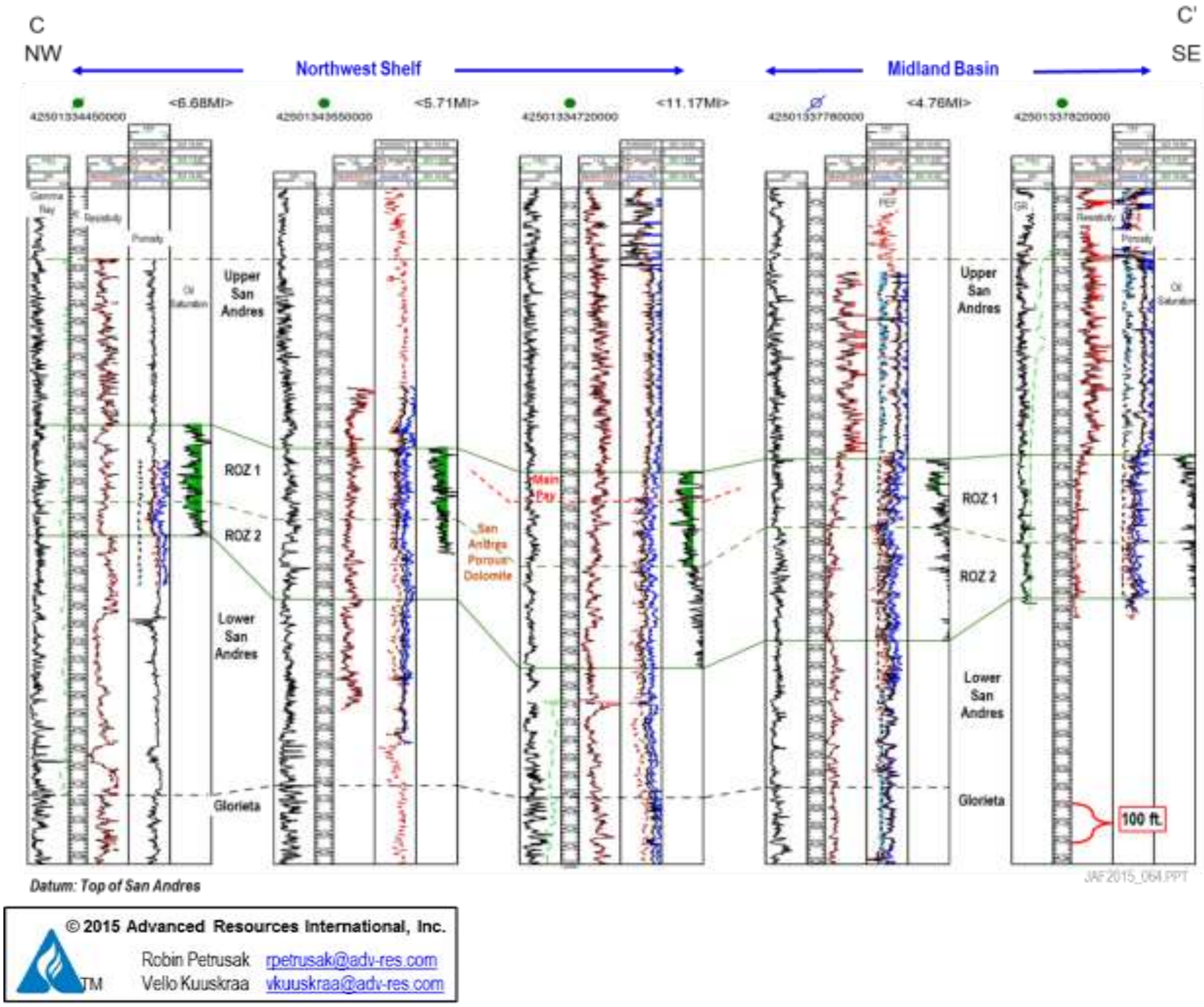
Robin Petrusak rpetrusaki@adv-res.com
Vello Kuuskraa vkuuskraa@adv-res.com

Exhibit 7.3B-3 Yoakum County SW-NE Cross-Section B-B'



Robin Petrusak rpetrusak@adv-res.com
Vello Kuuskraa vkuuskraa@adv-res.com

Exhibit 7.3B-4 Yoakum County NW-SE Cross-Section C-C’



Track 4 on the right shows the calculated oil saturation. Calculated oil saturations between 25 percent and 45 percent are shaded in dark green; calculated oil saturations between 45 percent and 65 percent are shaded in light green; and oil saturation greater than 65 percent, typically present in only the Main Pay Zone, are shaded in black.

The base of the ROZ is generally picked at the point where either calculated oil saturation or apparent porosity (or both) diminish in the Lower San Andres. If a Lower San Andres limestone is prominent, the top of the limestone defines the base of the ROZ.

The San Andres ROZ net pay in Yoakum County is extensive but varies greatly, ranging from 200 to 380 feet on the Northwest Shelf in the central and southern portions of the county. Oil saturations and porosity also tend to be relatively favorable in this geologic setting. In the western portion of the county, the net pay of the ROZ interval becomes thinner and tends to have lower oil saturation.

7.3B.4 Yoakum County "Type Log"

A "type log" was selected from the Yoakum County study wells to illustrate the ROZ resource analysis undertaken for the county. Exhibit 7.3B-5 provides a close-up display of calculated porosity and oil saturation for the ROZ in the "type log." The "type log" is intended to illustrate the two distinct San Andres ROZ resource intervals - - ROZ "1" in the upper portion of the Lower San Andres porous dolomite, and ROZ "2" in the lower portion of the Lower San Andres porous dolomite. In the "type log", these two intervals are distinguished by gamma ray and resistivity log character and by the calculated oil saturation.

Sonic porosity, shown in black, was used to calculate oil in-place for this well. Uncorrected neutron and density porosity curves are shown to illustrate the change in lithology below the ROZ, from porous dolomite to limestone. In this "type log", the porosity is fairly uniform but low through the ROZ. The calculated oil saturation diminishes at the base of ROZ "1" at approximately 5,550 feet. This is due to the distinct reduction in apparent resistivity, which is clearly shown on the log. From the gamma ray curve, one also observes that the ROZ "2" interval appears to have more shale and thinner interbeds of porous dolomite compared to ROZ "1". The base of the ROZ is picked at 5,720 feet, which is the approximate depth of a change in lithology from porous dolomite to a thick section of interbedded limestone, dolomitic limestone and shale/ siltstone above the Lower San Andres limestone. The Lower San Andres limestone in this "type log" is shown in cross-section B-B' (Exhibit 7.3B-3).

The oil saturation for the "type log" ROZ was calculated using the following Archie parameters - - 'm' of 2.3, 'n' of 3, 'a' of 1, and formation water resistivity (R_w) of 0.045 ohm-m. A porosity cut-off of 6 percent was applied to define net pay in the ROZ. Intervals identified as ROZ pay are shown by the red "pay" flag in Track 1 of Exhibit 7.3B-5. (Note that some of the apparent higher oil saturations, in intervals of low porosity, are excluded.)

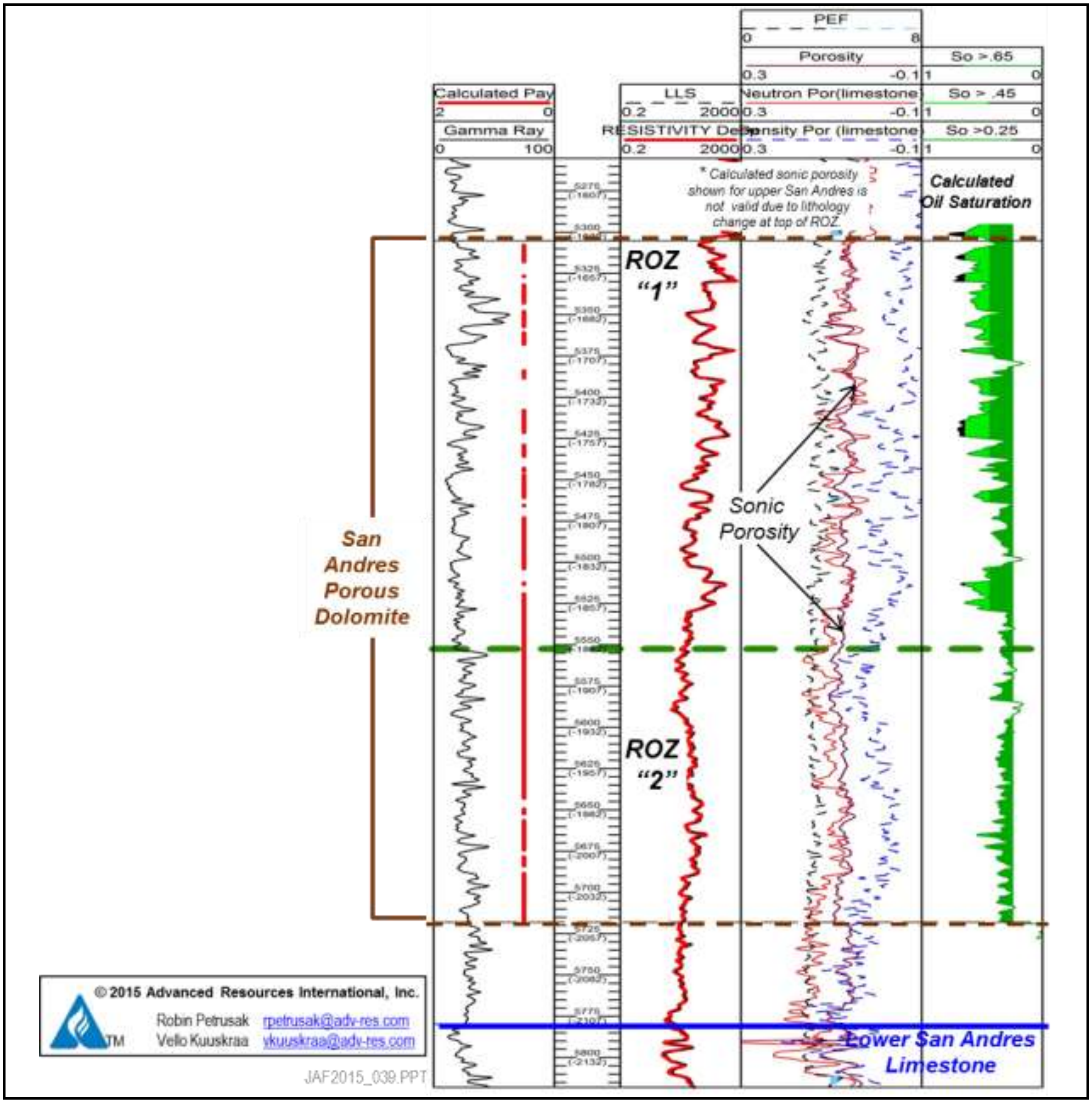
For ROZ "1," the average porosity of net pay is 7.4% and average oil saturation of net pay is 44%. Note that the highest calculated oil saturations occur at the top of ROZ "1". For ROZ "2", the average porosity of net pay is 8.1% and average oil saturation is 32%. Consequently, as discussed in Section 7.3 of the report, the ROZ "1" interval in this "type log" is characterized as "lower quality." Core analysis from the Bennett Ranch Unit of the Wasson Field was used to help establish log analysis parameters for the ROZ interval in Yoakum County.

7.3B.5 Partitioning the Yoakum County ROZ "Fairway" Resource

The ROZ "fairway" in Yoakum County is partitioned into four distinct areas, as illustrated in Exhibit 7.3B-1. Individual ROZ "fairway" resource assessments were undertaken for each of the four partitioned areas. The outlines of the four partitioned areas were guided by the current structure and the prominent features of the Permian Basin within the Yoakum County San Andres ROZ "fairway" study area.

- Partition #1. Covers a 73,000 acre (114 mi^2) area of western Yoakum County. A portion of the Roberts Unit of the Wasson oil field, covering 4,500 acres, has been excluded from the ROZ "fairway" resource assessment area for Partition #1.
- Partition #2. Covers a 120,000 acre (188 mi^2) area of northern Yoakum County.
- Partition #3. Covers a 129,000 acre (202 mi^2) area of central Yoakum County. The area encompassed by Brahaney (8,400 acres), Prentice (4,800 acres), Sable (3,200 acres) and Ownby (2,500 acres) oil fields has been excluded from the ROZ "fairway" resource assessment for Partition #3.
- Partition #4. Covers a 99,000 acre (155 mi^2) area of southern Yoakum County. The area encompassed by Wasson (59,000 acres), Reeves (6,200 acres), and West (2,800 acres) oil fields has been excluded from the ROZ "fairway" resource assessment for Partition #4.

Exhibit 7.3B-5 Type Log For Yoakum County San Andres ROZ "Fairway"



Source: Petrusak, R. and V.A. Kuuskraa, 2014, ROZ Fairway Resources of the Permian Basin: A Four-County Resource Assessment, slide no. 97, presentation prepared for Research Partnership to Secure Energy for America (RPSEA), June 25, 2014

Yoakum County covers a 512,400 acre (801 mi^2) area of the Permian Basin. A total of 91,400 acres (143 mi^2) under the structural closure of existing San Andres oil fields has been excluded, leaving a remaining ROZ assessment area of 421,000 acres (658 mi^2), Exhibit 7.3B-6.

Exhibit 7.3B-6 Yoakum County ROZ "Fairway" Partitions

Partition	Total Area (Acres)	Excluded Area (Acres)	Assessment Area (Acres)
#1	77,500	4,500	73,000
#2	120,000	-	120,000
#3	147,900	18,900	129,000
#4	167,000	68,000	99,000
Total	512,400	91,400	421,000

Source: Advanced Resources International, 2015.

7.3B.6 Size and Quality of the Yoakum County ROZ "Fairway" Resource

Yoakum County, Texas holds 20.7 billion barrels of oil in-place in the San Andres ROZ "fairway", outside the structural closure of the existing oil fields. The oil in-place and resource quality values provided for each of the four partitions for Yoakum County are shown in Exhibit 7.3B-7.

- Higher Quality ROZ "Fairway" Resources. A significant portion of the San Andres ROZ "fairway" oil in-place in Yoakum County of 17.6 billion barrels has "higher quality" reservoir properties (porosity greater than 8% and oil saturation equal to or greater than 25%), offering promise for commercial development of the ROZ resource with by-product storage of CO_2.
- Lower Quality ROZ "Fairway" Resources. The remainder of the San Andres ROZ "fairway" oil in-place in Yoakum County of 4.5 billion barrels has "lower quality" reservoir properties (porosity equal to or less than 8% and/or oil saturation of less than 25%), offering large volumes of pore space for storage of CO_2 with by-product oil recovery.

Exhibit 7.3B-7 Yoakum County San Andres ROZ "Fairway" Resource In-Place (Billion Barrels)

Partitions	ROZ 1			ROZ 2			Total		
	Higher Quality	Lower Quality	Total	Higher Quality	Lower Quality	Total	Higher Quality	Lower Quality	Total
#1	0.17	0.67	0.84	-	0.28	0.28	0.17	0.95	1.12
#2	3.89	0.54	4.43	4.57	-	4.57	8.46	0.54	9.00
#3	2.95	1.64	4.59	1.74	0.68	2.42	4.69	2.32	7.01
#4	2.53	0.04	2.57	0.22	0.78	1.00	2.75	0.82	3.57
Total	9.54	2.89	12.43	6.53	1.74	8.27	16.07	4.63	20.70

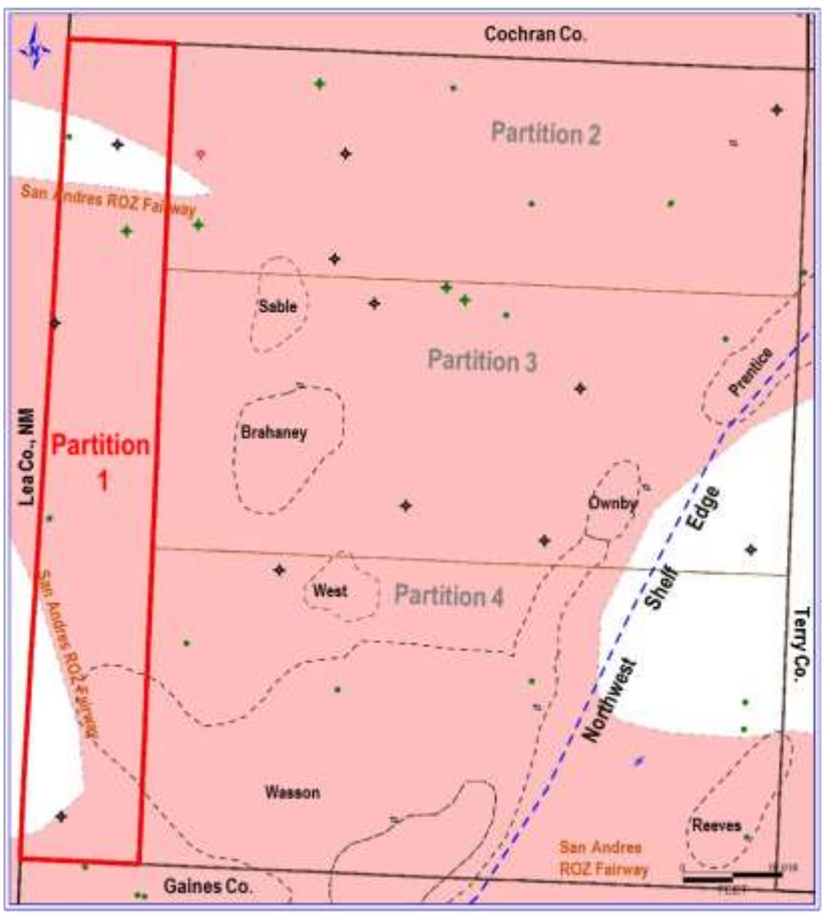
Source: Advanced Resources International, 2015.

7.3B.7 Partition #1. Western Yoakum County

Geologic Setting

Partition #1, located in western Yoakum County, covers a San Andres ROZ "fairway" area (outside the structural limits of existing oil fields) of 73,000 acres, Exhibit 7.3B-8. The partition area excludes the western portion of the Wasson oil field (4,500 acres). Except for two small areas in the northern and southern portion of the county, Partition #1 is located within the previously established San Andres ROZ "fairway" boundaries, on the Northwest Shelf of the Permian Basin.

Exhibit 7.3B-8 San Andres ROZ "Fairway" Partition #1, Yoakum County



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Robin Petrusak rpetrusak@adv-res.com
Vello Kuuskraa vkuuskraa@adv-res.com

Source: Advanced Resources International and Melzer Consulting, 2015.

The San Andres ROZ "fairway" reservoir interval in Partition #1 of Yoakum County has a net thickness that ranges from 20 to 190 feet, within a gross interval of 310 to 370 feet (including ROZ 1 and ROZ 2). The ROZ interval has a porosity of 6% to 11% and holds an oil saturation that ranges from below 20% to above 40%. Oil saturation for the study wells in Partition #1 was calculated using Archie parameters: 'm' = 2.3; 'n' = 2.3; 'a' = 1; Rw = 0.029 ohm-m.

7.3B.8 Analytical ROZ Reservoir Units

A series of five well log-based reservoir data sets plus a series of working level cross-sections were used to further divide the San Andres ROZ "fairway" resource in Partition #1 of Yoakum County into three analytical ROZ "fairway" reservoir units, as set forth below:

- A "higher quality" (HQ) ROZ #1 (Upper ROZ) interval
- A "lower quality" (LQ) ROZ #1 (Upper ROZ) interval
- A "lower quality" (LQ) ROZ #2 (Lower ROZ) interval

A "higher quality" analytical ROZ "fairway" reservoir unit has an average porosity greater than 8% and an average oil saturation greater than 25% for its net pay. A "lower quality" analytical ROZ "fairway" reservoir unit has an average porosity less than 8% and/or an average oil saturation less than 25% for its net pay.

A major purpose of the separation of the ROZ "fairway" resource into quality-based analytical reservoir units is to help establish the geological settings where: (1) the ROZ interval may have potential for commercial oil recovery with by-product storage of CO_2, and (2) where the ROZ interval may serve primarily as a location for storage of CO_2 with by-product production of oil.

The average volumetric reservoir properties for the three analytical San Andres ROZ "fairway" reservoir units of Partition #1 of Yoakum County are provided on Exhibit 7.3B-9.

7.3B.9 ROZ Oil In-Place

The San Andres ROZ "fairway" in Partition #1 of Yoakum County contains 1.12 billion barrels of oil in-place, Exhibit 7.3B-10. Only a modest portion of the ROZ oil in-place (0.17 billion barrels) meets the "higher" ROZ resource quality criteria, offering potential for commercial oil recovery with by-product storage of CO_2. The remainder of the ROZ oil in-place of 0.95 billion barrels meets the "lower" resource quality criteria, offering pore space for the storage of CO_2 with by-product production of oil.

Exhibit 7.3B-9 Average San Andres ROZ "Fairway" Reservoir Properties: Partition #1, Yoakum County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Gross Thickness (ft)	209	206	-	125
Net Pay (ft)	56	78	-	29
Avg. Porosity (fraction)	0.092	0.081	-	0.083
Avg. Oil Saturation (fraction)	0.36	0.30	-	0.26
Avg. Formation Volume Factor	1.28	1.28	-	1.28
OIP (B/AF, for net pay)	201	147	-	131

Source: Advanced Resources International, 2015

Exhibit 7.3B-10 San Andres ROZ "Fairway" Oil In-Place: Partition #1, Yoakum County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Oil In-Place (B/Acre)	11,260	11,470	-	3,800
Area Extent (Acres)	15,000	58,000	-	73,000
Oil In-Place (Billion Barrels)	0.17	0.67	-	0.28

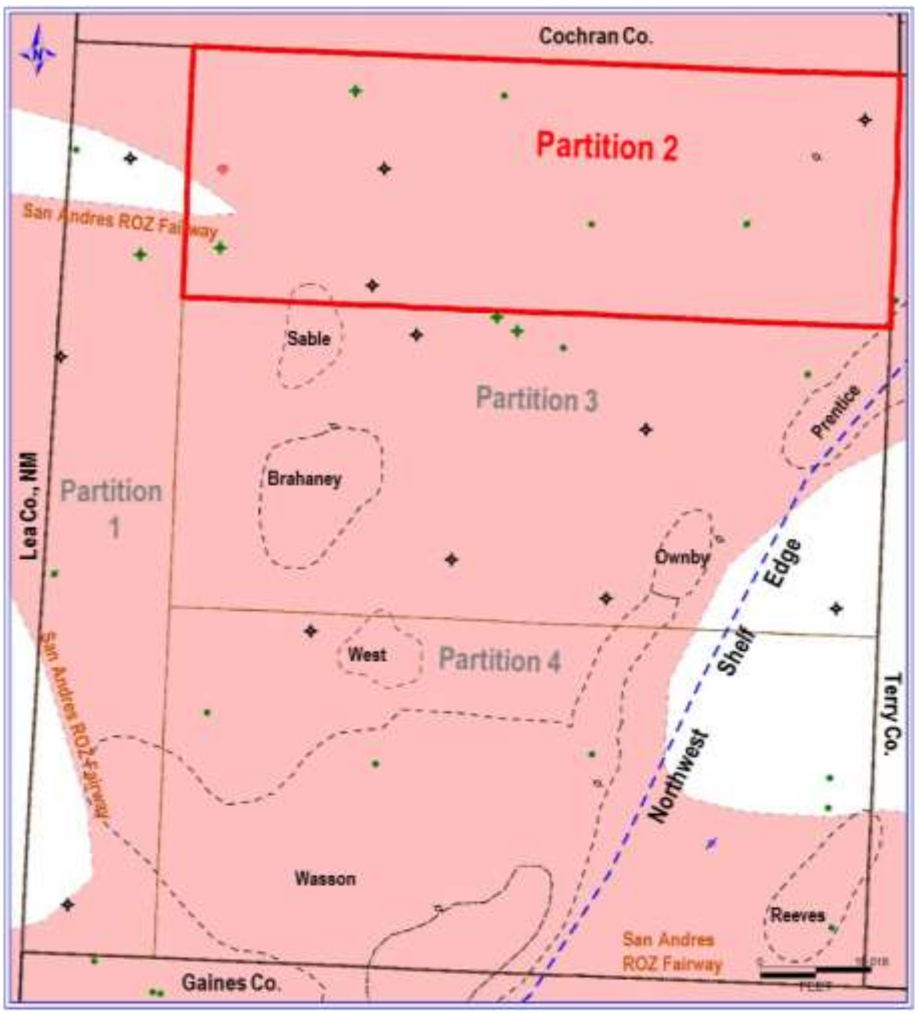
Source: Advanced Resources International, 2015

7.3B.10 Partition #2. Northern Yoakum County

Geologic Setting

Partition #2, located in northern Yoakum County, covers a San Andres ROZ “fairway” area (outside the structural limits of existing oil fields) of 120,000 acres, Exhibit 7.3B-11. The partition area does not contain any major San Andres oil fields. Partition #2 is located within the previously established San Andres ROZ “fairway” boundaries, on the Northwest Shelf of the Permian Basin.

Exhibit 7.3B-11 San Andres ROZ “Fairway” Partition #2, Yoakum County



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Robin Petrusak rpetrusak@adv-res.com
Vello Kuuskraa vkuuskraa@adv-res.com

Source: Advanced Resources International and Melzer Consulting, 2015.

The San Andres ROZ “fairway” reservoir interval in Partition #2 of Yoakum County has a net thickness that ranges from 160 to 370 feet, within a gross interval of 190 to 400 feet (including ROZ 1 and ROZ 2). The ROZ interval has a porosity of 9% to 13% and holds a residual oil saturation that ranges from 30% to above 40%. Oil saturation for the study wells in Partition #2 was calculated using Archie parameters: ‘m’ = 2.3; ‘n’ = 2.3; ‘a’ = 1; Rw = 0.038 ohm-m.

7.3B.11 Analytical ROZ Reservoir Units

A series of nine well log-based reservoir data sets plus a series of working level cross-sections were used to further divide the San Andres ROZ “fairway” resource in Partition #2 of Yoakum County into three analytical ROZ “fairway” reservoir units, as set forth below:

- A “higher quality” (HQ) ROZ #1 (Upper ROZ) interval
- A “lower quality” (LQ) ROZ #1 (Upper ROZ) interval
- A “higher quality” (HQ) ROZ #2 (Lower ROZ) interval

A “higher quality” analytical ROZ “fairway” reservoir unit has an average porosity greater than 8% and an average oil saturation greater than 25% for its net pay. A “lower quality” analytical ROZ “fairway” reservoir unit has an average porosity less than 8% and/or an average oil saturation less than 25% for its net pay.

A major purpose of the separation of the ROZ “fairway” resource into quality-based analytical reservoir units is to help establish the geological settings where: (1) the ROZ interval may have potential for commercial oil recovery with by-product storage of CO_2, and (2) where the ROZ interval may serve primarily as a location for storage of CO_2 with by-product production of oil.

The average volumetric reservoir properties for the three analytical San Andres ROZ “fairway” reservoir units of Partition #1 of Yoakum County are provided on Exhibit 7.3B-12.

Exhibit 7.3B-12 Average San Andres ROZ "Fairway" Reservoir Properties: Partition #2, Yoakum County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Gross Thickness (ft)	196	265	157	-
Net Pay (ft)	170	210	123	-
Avg. Porosity (fraction)	0.105	0.089	0.116	-
Avg. Oil Saturation (fraction)	0.36	0.24	0.44	-
Avg. Formation Volume Factor	1.28	1.28	1.28	-
OIP (B/AF, for net pay)	229	130	310	-

Source: Advanced Resources International, 2015

7.3B.12 ROZ Oil In-Place

The San Andres ROZ "fairway" in Partition #2 of Yoakum County contains 9.00 billion barrels of oil in-place, Exhibit 7.3B-13. The bulk of the ROZ oil in-place (8.46 billion barrels) meets the "higher" ROZ resource quality criteria, offering the potential for commercial oil recovery with by-product storage of CO_2. The remainder of the ROZ oil in-place of 0.54 billion barrels meets the "lower" resource quality criteria, offering pore space for the storage of CO_2 with by-product production of oil.

Exhibit 7.3B-13 San Andres ROZ "Fairway" Oil In-Place: Partition #2, Yoakum County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Oil In-Place (B/Acre)	38,930	27,300	38,130	-
Area Extent (Acres)	100,000	20,000	120,000	-
Oil In-Place (Billion Barrels)	3.89	0.54	4.57	-

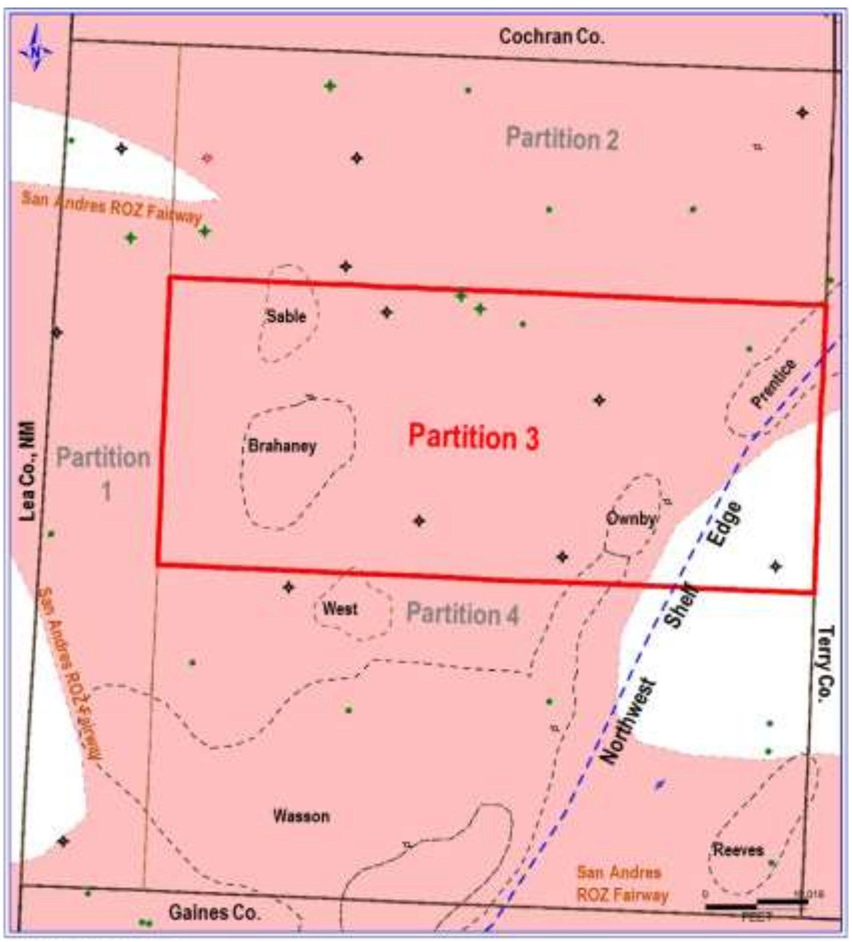
Source: Advanced Resources International, 2015

7.3B.13 Partition #3. Central Yoakum County

Geologic Setting

Partition #3, located in central Yoakum County, covers a San Andres ROZ "fairway" area (outside the structural limits of existing oil fields) of 129,000 acres, Exhibit 7.3B-14. The partition area excludes several large oil fields such as Brahaney, Prentice, Sable, and Ownby (18,900 acres). Except for a small area on the eastern portion of the county, Partition #3 is located within the previously established San Andres ROZ "fairway" boundaries and is located on the prograding on the Northwest Shelf of the Permian Basin.

Exhibit 7.3B-14 San Andres ROZ "Fairway" Partition #3, Yoakum County



JAF2015_056.PPT

Robin Petrusak rpetrusak@adv-res.com
Vello Kuuskraa vkuuskraa@adv-res.com

Source: Advanced Resources International and Melzer Consulting, 2015.

The San Andres ROZ "fairway" reservoir interval in Partition #3 of Yoakum County has a net thickness that ranges from 170 to 430 feet, within a gross interval of 350 to 650 feet. The ROZ interval has a porosity of 8% to 12% and holds an oil saturation that ranges from 20% to 40%. Oil saturation for most of the study wells in Partition #3 was calculated using Archie parameters: 'm' = 2.3; 'n' = 2.3; 'a' = 1; Rw = 0.045 ohm-m. For some wells, the parameter 'n' was increased to '3'.

7.3B.14 Analytical ROZ Reservoir Units

A series of nine well log-based reservoir data sets plus a series of working level cross-sections were used to further divide the San Andres ROZ "fairway" resource in Partition #3 of Yoakum County into six analytical ROZ "fairway" reservoir units, as set forth below:

Partition #3A

- A "higher quality" (HQ) ROZ #1 (Upper ROZ) interval
- A "lower quality" (LQ) ROZ #1 (Upper ROZ) interval
- A "higher quality" (HQ) ROZ #2 (Lower ROZ) interval
- A "lower quality" (LQ) ROZ #2 (Lower ROZ) interval

Partition #3B

- A "lower quality" (LQ) ROZ #1 (Upper ROZ) interval
- A "higher quality" (HQ) ROZ #2 (Lower ROZ) interval

A "higher quality" analytical ROZ "fairway" reservoir unit has an average porosity greater than 8% and an average oil saturation greater than 25% for its net pay. A "lower quality" analytical ROZ "fairway" reservoir unit has an average porosity less than 8% and/or an average oil saturation less than 25% for its net pay.

A major purpose of the separation of the ROZ "fairway" resource into quality-based analytical reservoir units is to help establish the geological settings where: (1) the ROZ interval may have potential for commercial oil recovery with by-product storage of CO_2, and (2) where the ROZ interval may serve primarily as a location for storage of CO_2 with by-product production of oil.

The volumetric reservoir properties for the six analytical San Andres ROZ "fairway" reservoir units of Partitions #3A and #3B of Yoakum County are provided on Exhibits 7.3B-15A and 7.3B-15B.

Exhibit 7.3B-15A Average San Andres ROZ "Fairway" Reservoir Properties: Partition #3A, Yoakum County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Gross Thickness (ft)	218	240	176	277
Net Pay (ft)	178	154	165	93
Avg. Porosity (fraction)	0.105	0.086	0.091	0.094
Avg. Oil Saturation (fraction)	0.40	0.26	0.33	0.14
Avg. Formation Volume Factor	1.26	1.26	1.26	1.26
OIP (B/AF, for net pay)	259	138	185	81

Source: Advanced Resources International, 2015

Exhibit 7.3B-15B Average San Andres ROZ "Fairway" Reservoir Properties: Partition #3B, Yoakum County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Gross Thickness (ft)	-	425	233	-
Net Pay (ft)	-	320	227	-
Avg. Porosity (fraction)	-	0.095	0.105	-
Avg. Oil Saturation (fraction)	-	0.22	0.50	-
Avg. Formation Volume Factor		1.26	1.26	
OIP (B/AF, for net pay)	-	129	323	-

Source: Advanced Resources International, 2015

7.3B-15 ROZ Oil In-Place

The San Andres ROZ “fairway” in Partition #3 of Yoakum County contains 7.01 billion barrels of oil in-place, Exhibit 7.3B-16A and Exhibit 7.3B-16B. The bulk of the ROZ oil in-place (4.69 billion barrels) meets the “higher” ROZ resource quality criteria, thus offering the potential for commercial oil recovery with by-product storage of CO_2. The remainder of the ROZ oil in-place of 2.32 billion barrels meets the “lower” resource quality criteria, offering pore space for the storage of CO_2 with by-product production of oil.

Exhibit 7.3B-16A San Andres ROZ “Fairway” Oil In-Place: Partition #3A, Yoakum County

	ROZ 1		ROZ 2	
	Higher Quality	**Lower Quality**	**Higher Quality**	**Lower Quality**
Oil In-Place (B/Acre)	46,100	21,250	30,520	7,530
Area Extent (Acres)	64,000	52,000	26,000	90,000
Oil In-Place (Billion Barrels)	2.95	1.10	0.79	0.68

Source: Advanced Resources International, 2015

Exhibit 7.3B-16B San Andres ROZ “Fairway” Oil In-Place: Partition #3B, Yoakum County

	ROZ 1		ROZ 2	
	Higher Quality	**Lower Quality**	**Higher Quality**	**Lower Quality**
Oil In-Place (B/Acre)	-	41,280	73,320	-
Area Extent (Acres)	-	13,000	13,000	-
Oil In-Place (Billion Barrels)	-	0.54	0.95	-

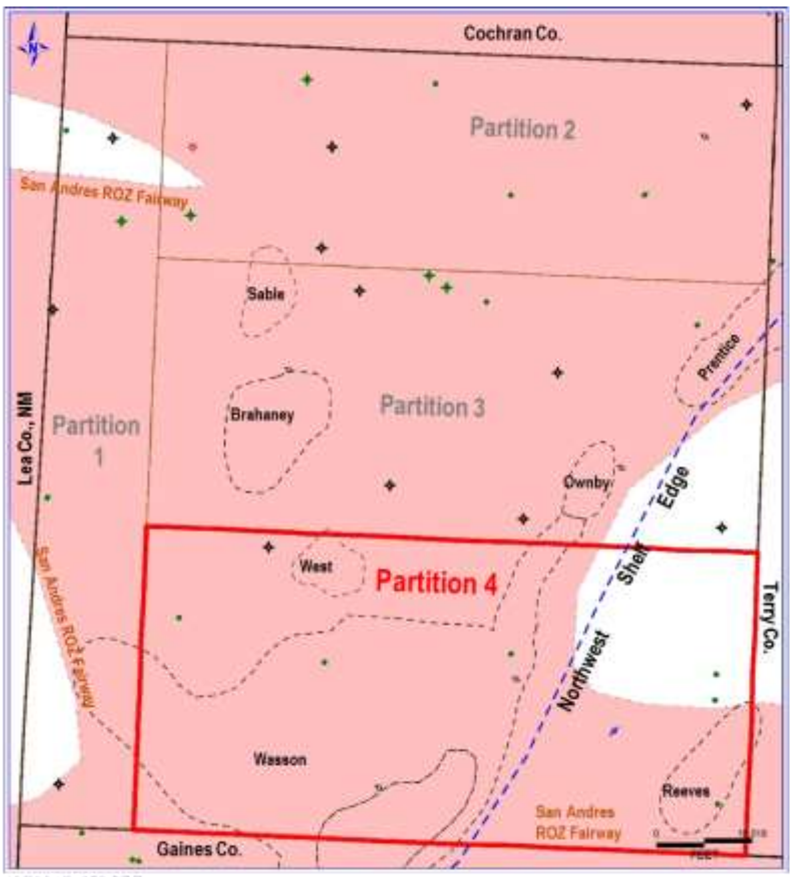
Source: Advanced Resources International, 2015

7.3B.16 Partition #4. Southern Yoakum County

Geologic Setting

Partition #4, located in southern Yoakum County, covers a San Andres ROZ “fairway” area (outside the structural limits of existing oil fields) of 99,000 acres, Exhibit 7.3B-17 The partition area excludes the Reeves, West and Wasson oil fields (68,000 acres). Partition #4 is located within the previously established San Andres ROZ “fairway” boundaries, except for a small area in the eastern portion of the county. Most of the partition is located on the Northwest Shelf of the Permian Basin; study wells in the southeast portion of Partition #4 are located off the Northwest Shelf in the Midland Basin.

Exhibit 7.3B-17 San Andres ROZ “Fairway” Partition #4, Yoakum County



JAF2015_056.PPT

Source: Advanced Resources International and Melzer Consulting, 2015.

The San Andres ROZ “fairway” reservoir interval in Partition #4 of Yoakum County has a net thickness that ranges from 160 to 290 feet, within a gross interval of 310 to 600 feet. The ROZ interval has a porosity of 8% to 14% and holds an oil saturation that ranges from below 20% to above 40%. Oil saturation for the study wells in the Northwest Shelf portion of Partition #4 was calculated using Archie parameters: ‘m’ = 2.3; ‘n’ = 3; ‘a’ = 1; Rw = 0.05 ohm-m. Oil saturation for the study wells in the Midland Basin portion of Partition #4 was calculated using Archie parameters: ‘m’ = 2.3; ‘n’ = 2.3; ‘a’ = 1; Rw = 0.045 ohm-m.

7.3B-17 Analytical ROZ Reservoir Units

A series of seven well log-based reservoir data sets plus a series of working level cross-sections were used to further divide the San Andres ROZ “fairway” resource in Partition #4 of Yoakum County into seven analytical ROZ “fairway” reservoir units, as set forth below:

Partition #4A

- A “higher quality” (HQ) ROZ #1 (Upper ROZ) interval
- A “higher quality” (HQ) ROZ #2 (Lower ROZ) interval
- A “lower quality” (LQ) ROZ #2 (Lower ROZ) interval

Partition #4B

- A “higher quality” (HQ) ROZ #1 (Upper ROZ) interval
- A “lower quality” (LQ) ROZ #1 (Upper ROZ) interval
- A “higher quality” (HQ) ROZ #2 (Lower ROZ) interval
- A “lower quality” (LQ) ROZ #2 (Lower ROZ) interval

A “higher quality” analytical ROZ “fairway” reservoir unit has an average porosity greater than 8% and an average oil saturation greater than 25% for its net pay. A “lower quality” analytical ROZ “fairway” reservoir unit has an average porosity less than 8% and/or an average oil saturation less than 25% for its net pay.

A major purpose of the separation of the ROZ “fairway” resource into quality-based analytical reservoir units is to help establish the geological settings where: (1) the ROZ interval may have potential for commercial oil recovery with by-product storage of CO_2, and (2) where the ROZ interval may serve primarily as a location for storage of CO_2 with by-product production of oil.

The volumetric reservoir properties for the three analytical San Andres ROZ “fairway” reservoir units of Partition #4A of Yoakum County are provided on Exhibit 7.3B-18A. The volumetric reservoir properties for the four analytical San Andres ROZ “fairway” reservoir units of Partition #4B of Yoakum County are provided on Exhibit 7.3B-18B.

Exhibit 7.3B-18A Average San Andres ROZ “Fairway” Reservoir Properties: Partition #4A, Yoakum County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Gross Thickness (ft)	196	-	371	200
Net Pay (ft)	115	-	41	115
Avg. Porosity (fraction)	0.096	-	0.092	0.108
Avg. Oil Saturation (fraction)	0.40	-	0.31	0.14
Avg. Formation Volume Factor	1.28	-	1.28	1.28
OIP (B/AF, for net pay)	230	-	173	92

Source: Advanced Resources International, 2015

Exhibit 7.3B-18B Average San Andres ROZ “Fairway” Reservoir Properties: Partition #4B, Yoakum County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Gross Thickness (ft)	192	182	124	260
Net Pay (ft)	133	95	70	103
Avg. Porosity (fraction)	0.118	0.124	0.148	0.127
Avg. Oil Saturation (fraction)	0.27	0.18	0.33	0.15
Avg. Formation Volume Factor	1.28	1.28	1.28	1.28
OIP (B/AF, for net pay)	193	135	296	115

Source: Advanced Resources International, 2015

7.3B.18 ROZ Oil In-Place

The San Andres ROZ “fairway” in Partition #4 of Yoakum County contains 3.57 billion barrels of oil in-place, Exhibit 7.3B-19A and Exhibit 7.3B-19B. The bulk of the ROZ oil in-place (2.75 billion barrels) meets the “higher” ROZ resource quality criteria, thus offering the potential for commercial oil recovery with by-product storage of CO_2. The remainder of the ROZ oil in-place of 0.82 billion barrels meets the “lower” resource quality criteria, offering pore space for the storage of CO_2 with by-product production of oil.

Exhibit 7.3B-19A San Andres ROZ “Fairway” Oil In-Place: Partition #4A, Yoakum County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Oil In-Place (B/Acre)	26,450	-	7,090	10,580
Area Extent (Acres)	90,000	-	22,500	67,500
Oil In-Place (Billion Barrels)	2.38	-	0.16	0.71

Source: Advanced Resources International, 2015

Exhibit 7.3B-19B San Andres ROZ “Fairway” Oil In-Place: Partition #4B, Yoakum County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Oil In-Place (B/Acre)	25,670	12,820	20,720	11,840
Area Extent (Acres)	6,000	3,000	3,000	6,000
Oil In-Place (Billion Barrels)	0.15	0.04	0.06	0.07

Source: Advanced Resources International, 2014

7.3C Terry County

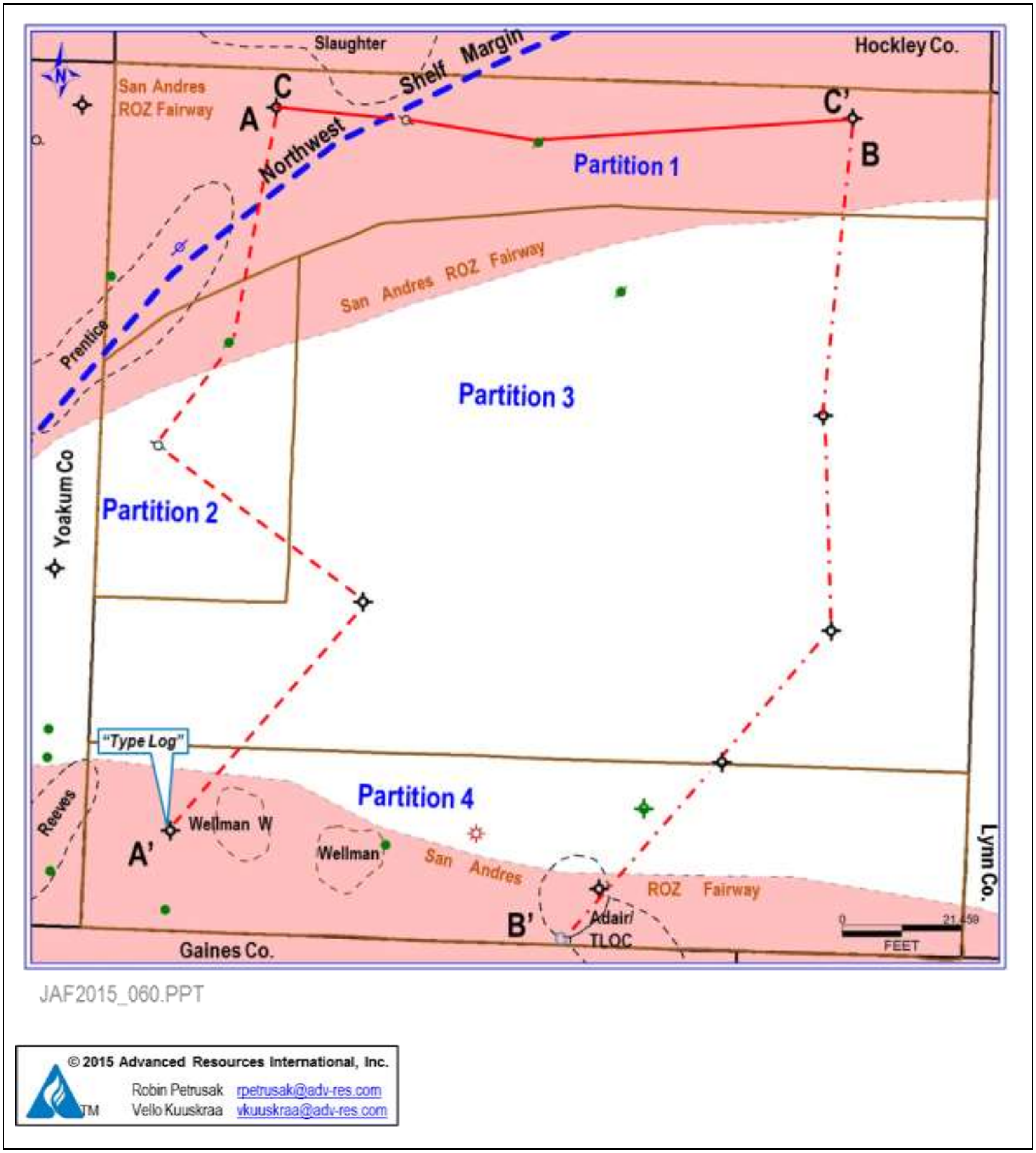
Geographic and Geologic Setting

Terry County, Texas covers a 570,600 acre (892 mi^2) area in the central part of the West Texas portion of the Permian Basin. The northwest corner of the county is located on the Northwest Shelf of the Permian Basin. The remainder of Terry County, east of this prominent Permian Basin feature, is located within the southward prograding Lower and Middle San Andres shelf margins of the Midland Basin.

Terry County contains several large San Andres oilfields - - Prentice, Welch and Adair/TLOC - - as well as the southern portion of the Slaughter oil field. The ROZ resources below these and other existing San Andres oil fields have been excluded from the resource assessment. Based on the currently mapped boundaries of the San Andres ROZ “fairway”, only the northern and southern portions of Terry County reside within the ROZ “fairway”.

The Terry County map, Exhibit 7.3C-1, shows: (1) the location of 19 study wells, 18 of which were used in the resource assessment; (2) the four ROZ “fairway” partitions; (3) the boundaries of the previously established ROZ “fairway”; (4) the outline of the NW Shelf; and (5) the prograding Lower and Middle San Andres shelf margins. The map also shows the locations of the major San Andres oil fields excluded from the San Andres ROZ “fairway” resource assessment.

Exhibit 7.3C-1 Terry County San Andres ROZ "Fairway": Geologic Partitions, Major Oil Fields and Study Well Locations



Source: Advanced Resources International, 2015.

7.3C.1 Terry County Cross-Sections

The delineation and characterization of the San Andres ROZ “fairway” interval in Terry County has drawn on the construction of a series of working cross-sections. Three of these cross-sections are included in this report.

- Terry Co. Cross-Section A-A’ (Exhibit 7.3C-2) provides a N-S view of the San Andres ROZ interval starting near the margin of the Northwest Shelf in the northwest corner of Terry Co., traversing south through the Midland Basin, and ending in the “merged” Roswell/Artesia fairway of the Midland Basin in southwest Terry Co.
- Terry Co. Cross-Section B-B’ (Exhibit 7.3C-3) provides a N-S view of the San Andres ROZ, to the east of Cross-Section A-A’. Cross-Section B-B’ starts in the Slaughter “fairway” of the Midland Basin in northeast Terry Co., traverses south through the Midland Basin, and ends in the Roswell/Artesia fairway of the Midland Basin in southcentral Terry Co.
- Terry Co. Cross-Section C-C’ (Exhibit 7.3C-4) provides a W-E view of the San Andres ROZ interval in northern Terry Co., extending from the Northwest Shelf to the Midland Basin.

Exhibit 7.3C-2 Terry County N-S Cross-Section A-A'

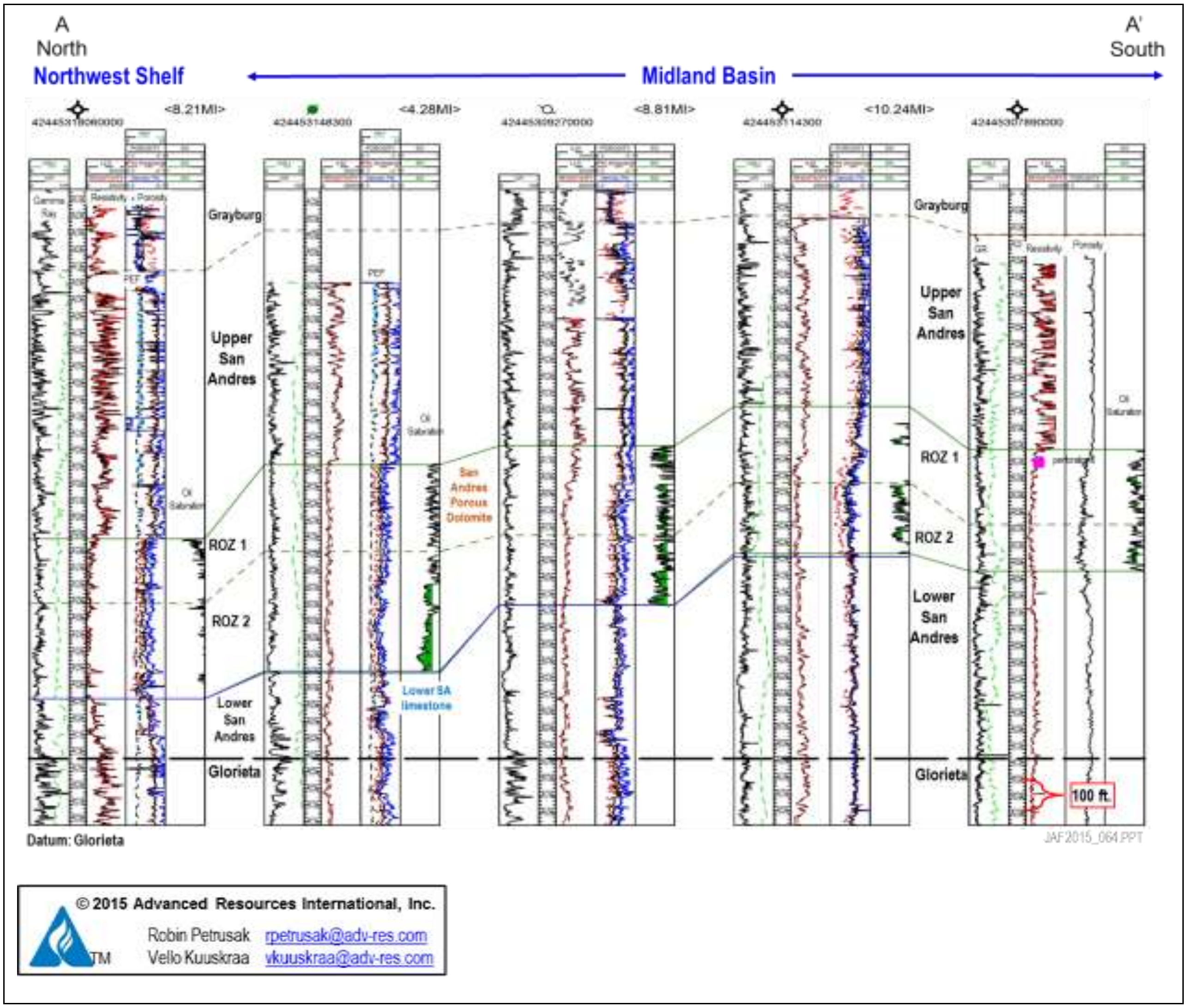
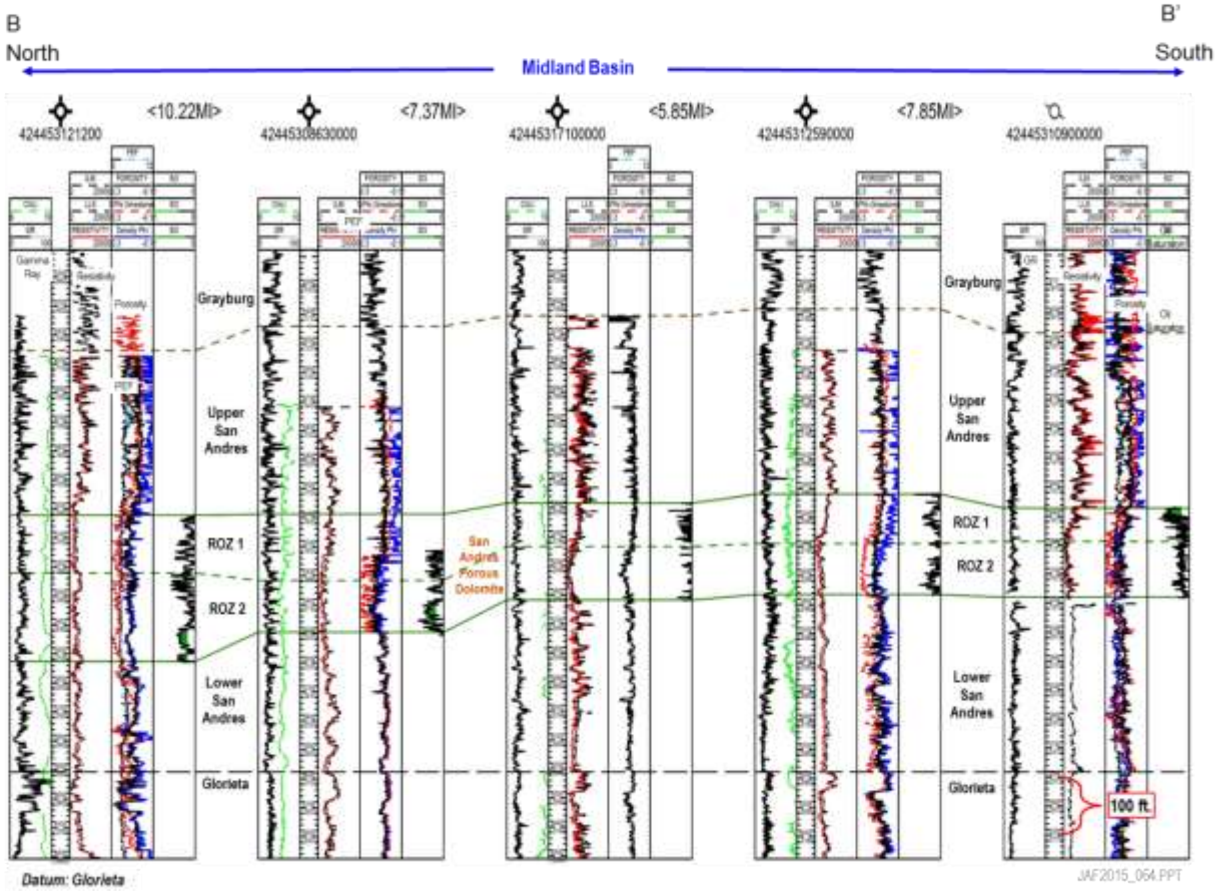


Exhibit 7.3C-3 Terry County N-S Cross-Section B-B’



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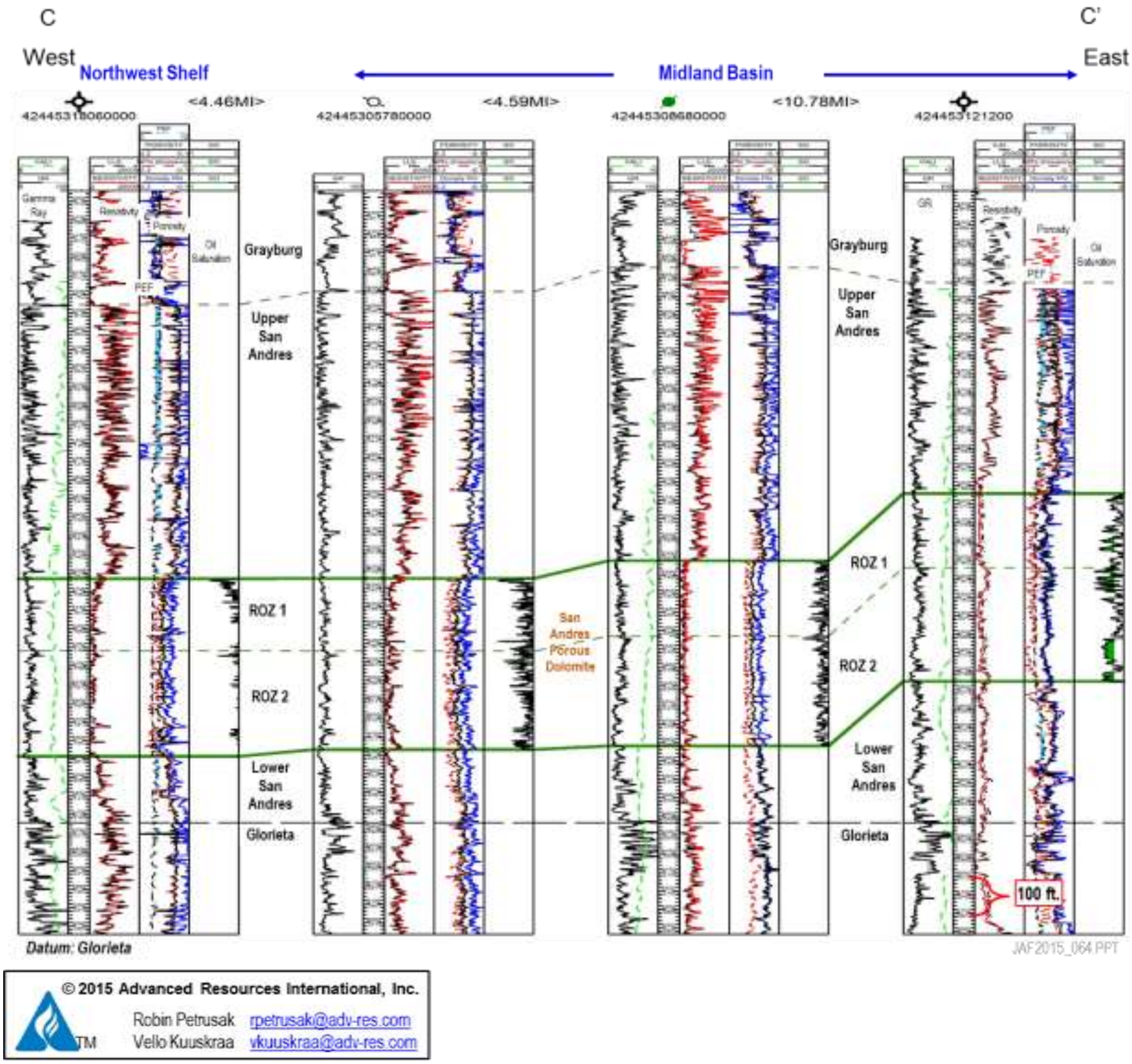
Robin Petrusak rpetrusak@adv-res.com
Vello Kuuskraa vkuuskraa@adv-res.com

Exhibit 7.3C-4 Terry County W-E Cross-Section C-C’



7.3C.2 Interpretation of Terry County Cross-Sections

For logs from existing oil fields with a Main Pay Zone, the top of the porous dolomite provides a marker for the top of the Main Pay Zone. For logs from the ROZ “fairway”, the top of the San Andres porous dolomite is picked as the top of the ROZ for this resource assessment. The porous dolomite intervals informally designated as ROZ “1” and ROZ “2” are illustrated on the cross-sections.

The cross-sections display gamma-ray and caliper logs in Track 1 on the left. Resistivity logs are shown in Track 2, with the deep resistivity log shown in red. Track 3 shows the porosity logs. Uncorrected neutron porosity (for limestone) is shown in red; uncorrected density porosity (for limestone) is shown in blue. The porosity curve used for the oil in-place calculation is shown in black. This porosity curve represents the “best available” porosity log for the ROZ, which may be a lithology-corrected neutron-density cross-plot porosity log, a lithology-corrected sonic porosity log, or a corrected neutron or density porosity log.

The photo-electric (PEF) curve, if available, is also displayed in Track 3. PEF values greater than “4” are shaded in blue. In the San Andres dolomite above the ROZ, high PEF values greater than “4” likely correspond to anhydrite. Within and below the ROZ interval, high PEF values generally indicate the presence of limestone or dolomitic limestone.

Track 4 on the right shows the calculated oil saturation. Calculated oil saturations between 25 percent and 40 percent are shaded in dark green; calculated oil saturations between 45 percent and 60 percent are shaded in light green; and oil saturation greater than 65 percent, typically present in only the Main Pay Zone, are shaded in black.

The base of the ROZ is generally picked at the point where either calculated oil saturation or apparent porosity (or both) diminish in the Lower San Andres. If a Lower San Andres limestone is prominent, the top of the limestone defines the lower boundary of the ROZ.

The ROZ interval and net pay in Terry County is extensive but varies greatly - - from tens of feet in the Midland Basin in the center of the county to several hundred feet in the Northwest Shelf Platform in the northern and western portions of the county. Except in selected areas, the oil saturations in the San Andres ROZ “fairway” of Terry County tend to be low.

7.3C.3 Terry County "Type Log"

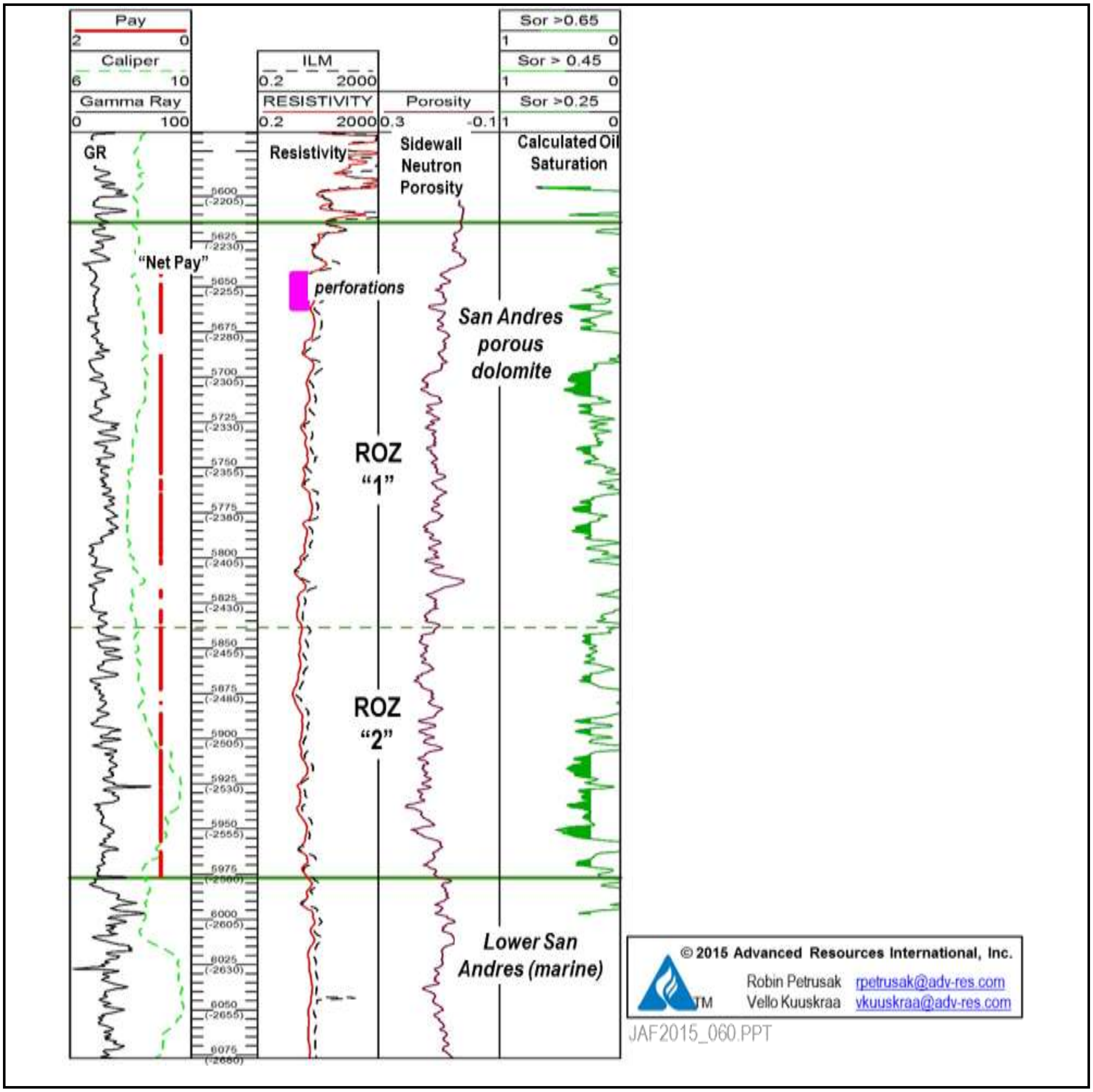
A "type log" was selected from the Terry County study wells to illustrate the ROZ resource analysis undertaken for the county. Exhibit 7.3C-5 provides a close-up display of calculated porosity and oil saturation for the ROZ in the "type log." The "type log" illustrates two distinct San Andres ROZ resource intervals - - ROZ "1" in the upper portion of the Lower San Andres porous dolomite, and ROZ "2" in the lower portion of the Lower San Andres porous dolomite.

The "type log" shows lithology-corrected sidewall neutron porosity through the San Andres porous dolomite. Porosity is fairly uniform through the ROZ "1" and increases in ROZ "2". Calculated oil saturation diminishes significantly at the base of ROZ "1". A second, higher oil saturated interval is shown at the base of ROZ "2". In this well, the base of the ROZ is defined by an apparent lithology change to predominately shale, representing the marine facies of the Lower San Andres in the Midland Basin. If available, additional data such as core, mud logs, or sample logs would assist on where to pick the base of the ROZ.

The oil saturation for the type log ROZ was calculated using the following Archie parameters - - 'm' of 2.3, 'n' of 2.3 'a' of 1, and formation water resistivity (Rw) of 0.045. A porosity cut-off of 6 percent was applied to define net pay in the ROZ. Intervals identified as ROZ pay are shown by the red "pay" flag in Track 1 of Exhibit 7.3C-5.

For ROZ "1," the average porosity of net pay is 11.3 % and average oil saturation of net pay is 21%. Note that the highest calculated oil saturations occur at the top of ROZ "1". As discussed in Section 2.4.5 of the report, the ROZ "1" resource in the "type log" is characterized as "lower quality" based on the calculated oil saturation of less than 25%. For ROZ "2", the average porosity of net pay is 14.4% and average oil saturation is 25%. Consequently, the ROZ "2" resource in the "type log" is characterized as "higher quality".

Exhibit 7.3C-5 Type Log For Terry County San Andres ROZ "Fairway"



Source: Advanced Resources International, 2014

7.3C.4 Partitioning the Terry County ROZ "Fairway" Resource

The ROZ "fairway" in Terry County is partitioned into four distinct areas, as illustrated in Exhibit 7.3C-1. Individual ROZ "fairway" resource assessments were undertaken for each of the four partitioned areas. The definition of the partitions was guided by the current structure and prominent features of the Permian Basin within the Terry County San Andres ROZ "fairway" study area.

- Partition #1. Covers 93,000 acre (145 mi^2) area of northern Terry County. Portions of the Slaughter (1,600 acres) and the Prentice oil fields (8,000 acres) have been excluded from the resource assessment area for Partition #1.
- Partition #2. Covers a 42,000 acre (66 mi^2) area of western Terry County. A small portion (1,200 acres) of the Prentice oil field has been excluded from the resource assessment area for Partition #2.
- Partition #3. Covers a 303,000 acre (473 mi^2) area of central Terry County.
- Partition #4. Covers a 111,000 acre (173 mi^2) area of southern Terry County. The area encompassed by the Wellman (4,900 acres) and Adair/TLOC (5,900 acres) oil fields has been excluded from the resource assessment area for Partition #4.

Terry County covers a 570,600 acre (892 mi^2) area of the Permian Basin. A total of 21,600 acres (34 mi^2) under the structural closure of existing San Andres oil fields has been excluded, leaving a remaining San Andres ROZ "fairway" assessment area of 549,000 acres (858 mi^2), Exhibit 7.3C-6.

Exhibit 7.3C-6 Terry County ROZ "Fairway" Partitions

Partition	Total Area (Acres)	Excluded Area (Acres)	Assessment Area (Acres)
#1	102,600	9,600	93,000
#2	43,200	1,200	42,000
#3	303,000	-	303,000
#4	121,800	10,800	111,000
Total	570,600	21,600	549,000

Source: Advanced Resources International, 2015.

7.3C.5 Size and Quality of the Terry County ROZ “Fairway” Resource

Terry County, Texas holds 17.9 billion barrels of oil in-place in the San Andres ROZ “fairway”, outside the structural closure of the existing oil fields. The oil in-place and resource quality values provided for each of the four partitions for Terry County are shown in Exhibit 7.3C-7.

- Higher Quality ROZ “Fairway” Resources. A significant portion of the San Andres ROZ “fairway” oil in-place in Terry County of 10.6 billion barrels has “higher quality” reservoir properties (porosity greater than 8% and oil saturation equal to or greater than 25%), offering promise for commercial development of the ROZ resource with by-product storage of CO_2.
- Lower Quality ROZ “Fairway” Resources. The remainder of the San Andres ROZ “fairway” oil in-place in Terry County of 7.3 billion barrels has “lower quality” reservoir properties (porosity equal to or less than 8% and/or oil saturation of less than 25%), offering important volumes of pore space for storage of CO_2 with by-product oil recovery.

Exhibit 7.3C-7 Terry County San Andres ROZ “Fairway” Resource In-Place (Billion Barrels)

Partitions	ROZ 1			ROZ 2			Total		
	Higher Quality	Lower Quality	Total	Higher Quality	Lower Quality	Total	Higher Quality	Lower Quality	Total
#1	0.00	1.60	1.60	0.75	0.92	1.67	0.75	2.52	3.27
#2	0.54	0.44	0.98	2.15	-	2.15	2.69	0.44	3.13
#3	0.18	1.44	1.62	4.90	1.09	5.99	5.08	2.53	7.61
#4	0.48	1.13	1.61	1.60	0.72	2.32	2.08	1.85	3.93
Total	**1.20**	**4.61**	**5.81**	**9.40**	**2.73**	**12.13**	**10.60**	**7.34**	**17.94**

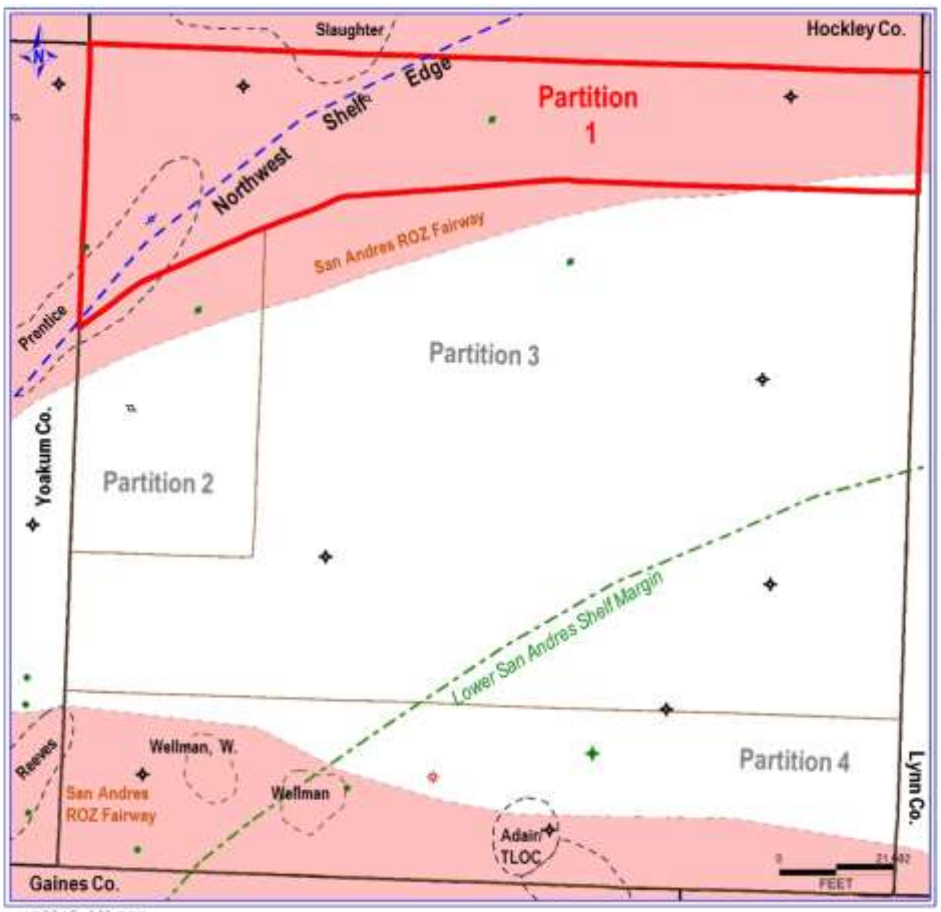
Source: Advanced Resources International, 2015.

7.3C.6 Partition #1. Northern Terry County

Geologic Setting

Partition#1, located in northern Terry County, covers a San Andres ROZ “fairway” area (outside the structural limits of existing oil fields) of 93,000 acres (145 mi^2), Exhibit 7.3C-8. The partition area excludes the small southern portion (1,600 acres) of the Slaughter oil field and the eastern portion (8,000 acres) of the Prentice oil field. Partition #1 is located within the previously established San Andres ROZ “fairway” boundaries. The Northwest Shelf of the Permian Basin is in the northwest portion of Partition #1 of Terry County.

Exhibit 7.3C-8 San Andres ROZ “Fairway” Partition #1, Terry County



JAF2015_060.PPT

Source: Advanced Resources International and Melzer Consulting, 2014.

The San Andres ROZ “fairway” reservoir interval in Partition #1 of Terry County has a net thickness that ranges from 150 to 430 feet, within a gross interval of about 600 feet. The ROZ interval has a porosity of 11% to 13% and holds low residual oil saturations that range from below 10% to above 20%. Oil saturation for the study wells in Partition #1 was calculated using Archie parameters: ‘m’ = 2.3; ‘n’ = 2.3 (Midland Basin) – 3.0 (NW Shelf); ‘a’ = 1; Rw = 0.03 – 0.04 ohm-m.

7.3C.7 Analytical ROZ Reservoir Units

A series of six well log-based reservoir data sets plus a set of working level cross-sections were used to further divide the San Andres ROZ “fairway” resource in Partition #1 of Terry County into three analytical ROZ “fairway” reservoir units, as set forth below:

- A “lower quality” (LQ) ROZ #1 (Upper ROZ) interval
- A “higher quality” (HQ) ROZ #2 (Lower ROZ) interval
- A “lower quality” (LQ) ROZ #2 (Lower ROZ) interval

A “higher quality” analytical ROZ “fairway” reservoir unit has an average porosity greater than 8% and an average oil saturation greater than 25% for its net pay. A “lower quality” analytical ROZ “fairway” reservoir unit has an average porosity less than 8% and/or an average oil saturation less than 25% for its net pay.

A major purpose of the separation of the ROZ “fairway” resource into quality-based analytical reservoir units is to help establish the geological settings where: (1) the ROZ interval may have potential for commercial oil recovery with by-product storage of CO_2, and (2) where the ROZ interval may serve primarily as a location for storage of CO_2 with by-product production of oil.

The volumetric reservoir properties for the three analytical San Andres ROZ “fairway” reservoir units of Partition #1 of Terry County are provided on Exhibit 7.3C-9.

Exhibit 7.3C-9 Average San Andres ROZ "Fairway" Reservoir Properties: Partition #1, Terry County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Gross Thickness (ft)	-	226	306	290
Net Pay (ft)	-	152	280	152
Avg. Porosity (fraction)	-	0.117	0.118	0.128
Avg. Oil Saturation (fraction)	-	0.16	0.25	0.10
Avg. Formation Volume Factor	-	1.28	1.28	1.28
OIP (B/AF, for net pay)	-	113	179	78

Source: Advanced Resources International, 2015

7.3C.8 ROZ Oil In-Place

The San Andres ROZ "fairway" in Partition #1 of Terry County contains 3.27 billion barrels of oil in-place, Exhibit 7.3C-10. Only a modest portion of the ROZ oil in-place (0.75 billion barrels) meets the "higher" ROZ resource quality criteria, offering the potential for commercial oil recovery with by-product storage of CO_2. The remainder of the ROZ oil in-place of 2.52 billion barrels meets the "lower" resource quality criteria, offering pore space for the storage of CO_2 with by-product production of oil.

Exhibit 7.3C-10 Average San Andres ROZ "Fairway" Oil In-Place: Partition #1, Terry County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Oil In-Place (B/Acre)	-	17,200	50,070	11,790
Area Extent (Acres)	-	93,000	15,000	78,000
Oil In-Place (Billion Barrels)	-	1.60	0.75	0.92

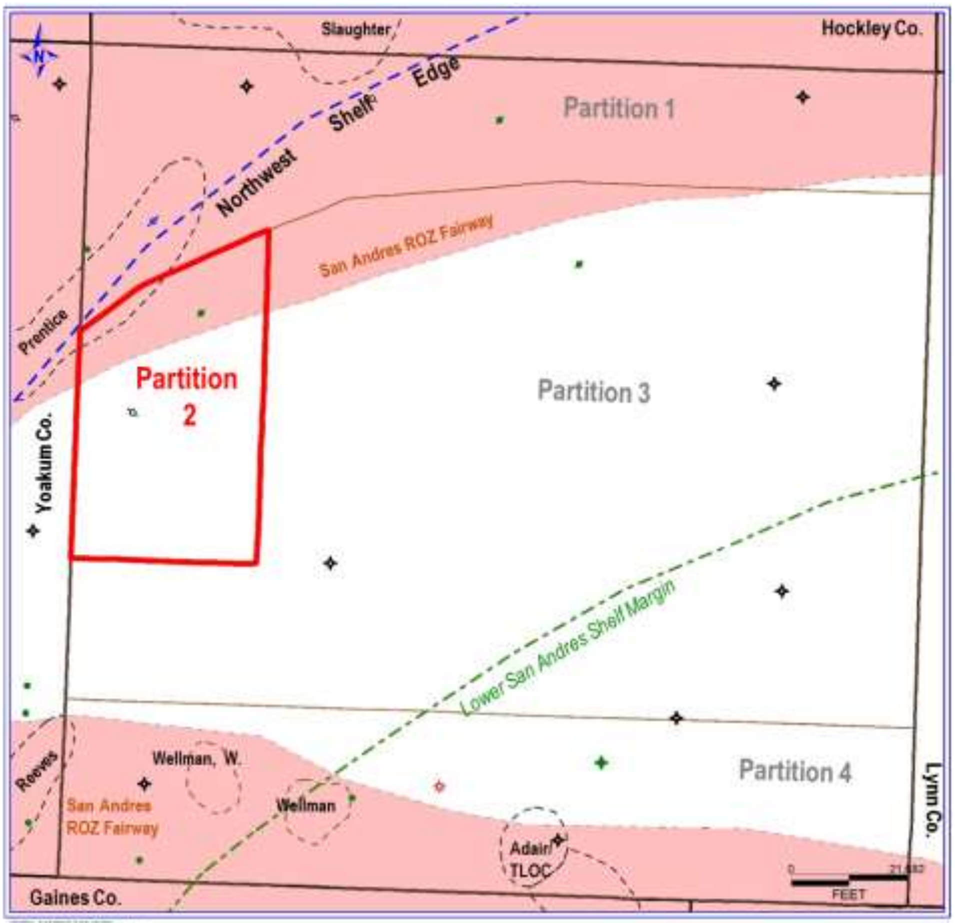
Source: Advanced Resources International, 2015

7.3C.9 Partition #2. Western Terry County

Geologic Setting

Partition#2, located in western Terry County, covers a San Andres ROZ “fairway” area (outside the structural limits of existing oil fields) of 42,000 acres (66 mi^2) , Exhibit 7.3C-11. The partition area partition excludes a portion (1,200 acres) of the Prentice oil field. Only a small area of Partition #2 is located within the previously established San Andres ROZ “fairway” boundaries in the western portion of the southeastward Prograding Midland Basin.

Exhibit 7.3C-11 San Andres ROZ “Fairway” Partition #2, Terry County



JAF2015_060.PPT

Source: Advanced Resources International and Melzer Consulting, 2015.

The San Andres ROZ “fairway” reservoir interval in Partition #2 of Terry County has a net thickness that ranges from 340 to 470 feet, within a gross interval of 480 to 630 feet. The ROZ interval has a porosity of 10% to 11% and holds moderate residual oil saturations that range below 25% to above 30%. Oil saturation for the study wells in Partition #2 was calculated using Archie parameters: ‘m’ and ‘n’ = 2.3; ‘a’ = 1; Rw = 0.04 ohm-m.

7.3C.10 Analytical ROZ Reservoir Units

A series of three well log-based reservoir data sets plus working level cross-sections were used to further divide the San Andres ROZ “fairway” resource in Partition #2 of Terry County into three analytical ROZ “fairway” reservoir units, as set forth below:

- A “higher quality” (HQ) ROZ #1 (Upper ROZ) interval
- A “lower quality” (LQ) ROZ #1 (Upper ROZ) interval
- A “higher quality” (HQ) ROZ #2 (Lower ROZ) interval

A “higher quality” analytical ROZ “fairway” reservoir unit has an average porosity greater than 8% and an average oil saturation greater than 25% for its net pay. A “lower quality” analytical ROZ “fairway” reservoir unit has an average porosity less than 8% and/or an average oil saturation less than 25% for its net pay.

A major purpose of the separation of the ROZ “fairway” resource into quality-based analytical reservoir units is to help establish the geological settings where: (1) the ROZ interval may have potential for commercial oil recovery with by-product storage of CO_2, and (2) where the ROZ interval may serve primarily as a location for storage of CO_2 with by-product production of oil.

The volumetric reservoir properties for the three analytical San Andres ROZ “fairway” reservoir units of Partition #1 of Terry County are provided on Exhibit 7.3C-12.

Exhibit 7.3C-12 Average San Andres ROZ "Fairway" Reservoir Properties: Partition #2, Terry County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Gross Thickness (ft)	267	253	294	-
Net Pay (ft)	143	198	234	-
Avg. Porosity (fraction)	0.095	0.103	0.113	-
Avg. Oil Saturation (fraction)	0.31	0.17	0.32	-
Avg. Formation Volume Factor	1.28	1.28	1.28	-
OIP (B/AF, for net pay)	178	106	219	-

Source: Advanced Resources International, 2015

7.3C.11 ROZ Oil In-Place

The San Andres ROZ "fairway" in Partition #2 of Terry County contains 3.13 billion barrels of oil in-place, Exhibit 7.3C-13. The bulk of the ROZ oil in-place (2.69 billion barrels) meets the "higher" ROZ resource quality criteria, thus offering the potential for commercial oil recovery with by-product storage of CO_2. The remainder of the ROZ oil in-place of 0.44 billion barrels meets the "lower" resource quality criteria, offering pore space for the storage of CO_2 with by-product production of oil.

Exhibit 7.3C-13 San Andres ROZ "Fairway" Oil In-Place: Partition #2, Terry County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Oil In-Place (B/Acre)	25,450	20,990	51,250	-
Area Extent (Acres)	21,000	21,000	42,000	
Oil In-Place (Billion Barrels)	0.54	0.44	2.15	

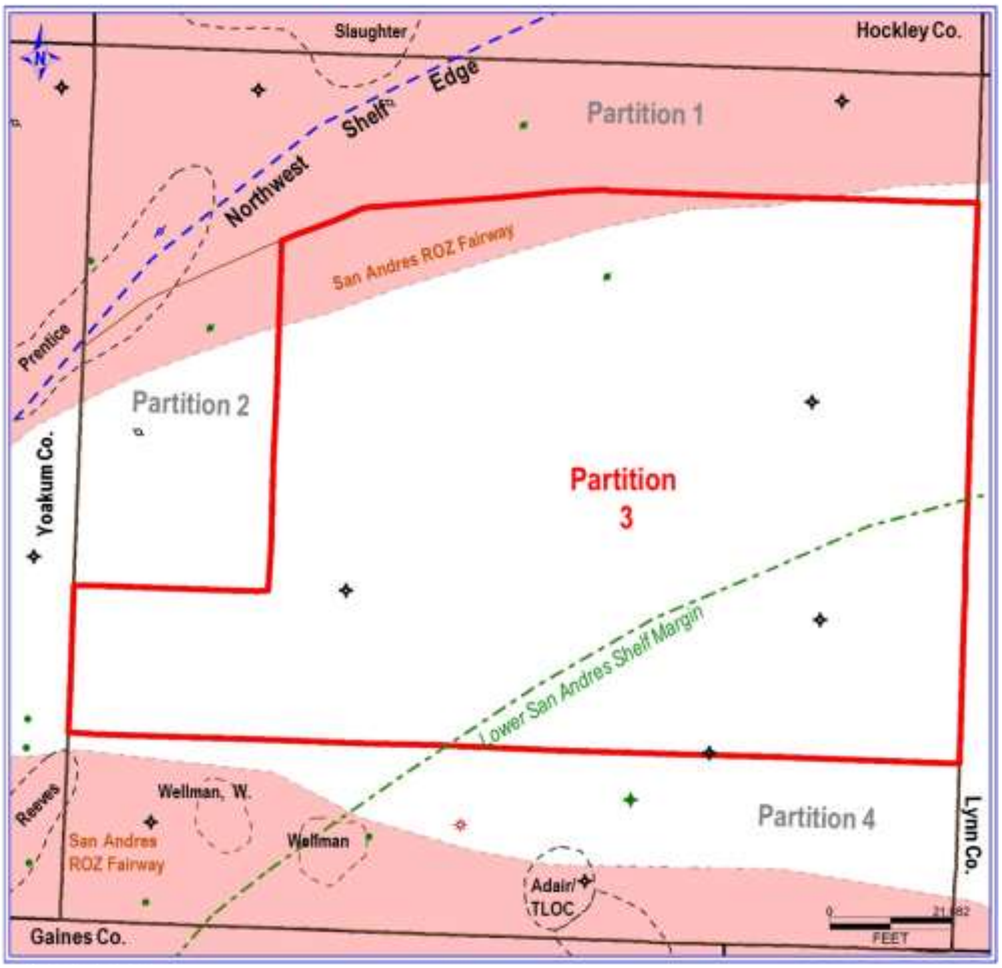
Source: Advanced Resources International, 2015

7.3C.12 Partition #3. Central Terry County

Geologic Setting

Partition#3, located in central Terry County, covers a San Andres ROZ “fairway” area (outside the structural limits of existing oil fields) of 303,000 acres (473 mi²), Exhibit 7.3C-14. The partition area does not contain any major San Andres oil fields. Partition #3 is located outside the previously established San Andres ROZ “fairway” boundaries, in the Midland Basin of the larger Permian Basin.

Exhibit 7.3C-14 San Andres ROZ “Fairway” Partition #3, Terry County



JAF2015_060.PPT

Source: Advanced Resources International and Melzer Consulting, 2015.

The San Andres ROZ “fairway” reservoir interval in Partition #3 of Terry County has a net thickness that ranges from 80 to 200 feet, within a gross interval of 370 to 380 feet. The ROZ interval has a porosity of 9% to 14% and holds relatively low oil saturations that range from below 15% to above 25%. Oil saturation for the study wells in Partition #3 was calculated using Archie parameters: ‘m’ = 2.3; ‘n’ = 2.3 (most wells); ‘a’ = 1; Rw = 0.045 – 0.05 ohm-m.

7.3C.13 Analytical ROZ Reservoir Units

A series of five well log-based reservoir data sets plus working level cross-sections were used to further divide the San Andres ROZ “fairway” resource in Partition #3 of Terry County into four analytical ROZ “fairway” reservoir units, as set forth below:

- A “higher quality” (HQ) ROZ #1 (Upper ROZ) interval
- A “lower quality” (LQ) ROZ #1 (Upper ROZ) interval
- A “higher quality” (HQ) ROZ #2 (Lower ROZ) interval
- A “lower quality” (LQ) ROZ #2 (Lower ROZ) interval

A “higher quality” analytical ROZ “fairway” reservoir unit has an average porosity greater than 8% and an average oil saturation greater than 25% for its net pay. A “lower quality” analytical ROZ “fairway” reservoir unit has an average porosity less than 8% and/or an average oil saturation less than 25% for its net pay.

A major purpose of the separation of the ROZ “fairway” resource into quality-based analytical reservoir units is to help establish the geological settings where: (1) the ROZ interval may have potential for commercial oil recovery with by-product storage of CO_2, and (2) where the ROZ interval may serve primarily as a location for storage of CO_2 with by-product production of oil.

The volumetric reservoir properties for the four analytical San Andres ROZ “fairway” reservoir units of Partition #3 of Terry County are provided on Exhibit 7.3C-15.

Exhibit 7.3C-15 Average San Andres ROZ "Fairway" Reservoir Properties: Partition #3, Terry County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Gross Thickness (ft)	229	159	194	180
Net Pay (ft)	22	58	125	77
Avg. Porosity (fraction)	0.082	0.105	0.133	0.136
Avg. Oil Saturation (fraction)	0.27	0.16	0.27	0.14
Avg. Formation Volume Factor	1.28	1.28	1.28	1.28
OIP (B/AF, for net pay)	134	102	218	115

Source: Advanced Resources International, 2015

7.3C.14 ROZ Oil In-Place

The San Andres ROZ "fairway" in Partition #3 of Terry County contains 7.61 billion barrels of oil in-place, Exhibit 7.3C-16. The bulk of the ROZ oil in-place (5.08 billion barrels) meets the "higher" ROZ resource quality criteria, thus offering the potential for commercial oil recovery with by-product storage of CO_2. The remainder of the ROZ oil in-place of 2.53 billion barrels meets the "lower" resource quality criteria, offering pore space for the storage of CO_2 with by-product production of oil.

Exhibit 7.3C-16 San Andres ROZ "Fairway" Oil In-Place: Partition #3, Terry County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Oil In-Place (B/Acre)	2,950	5,920	27,250	8,860
Area Extent (Acres)	60,000	243,000	180,000	123,000
Oil In-Place (Billion Barrels)	0.18	1.44	4.90	1.09

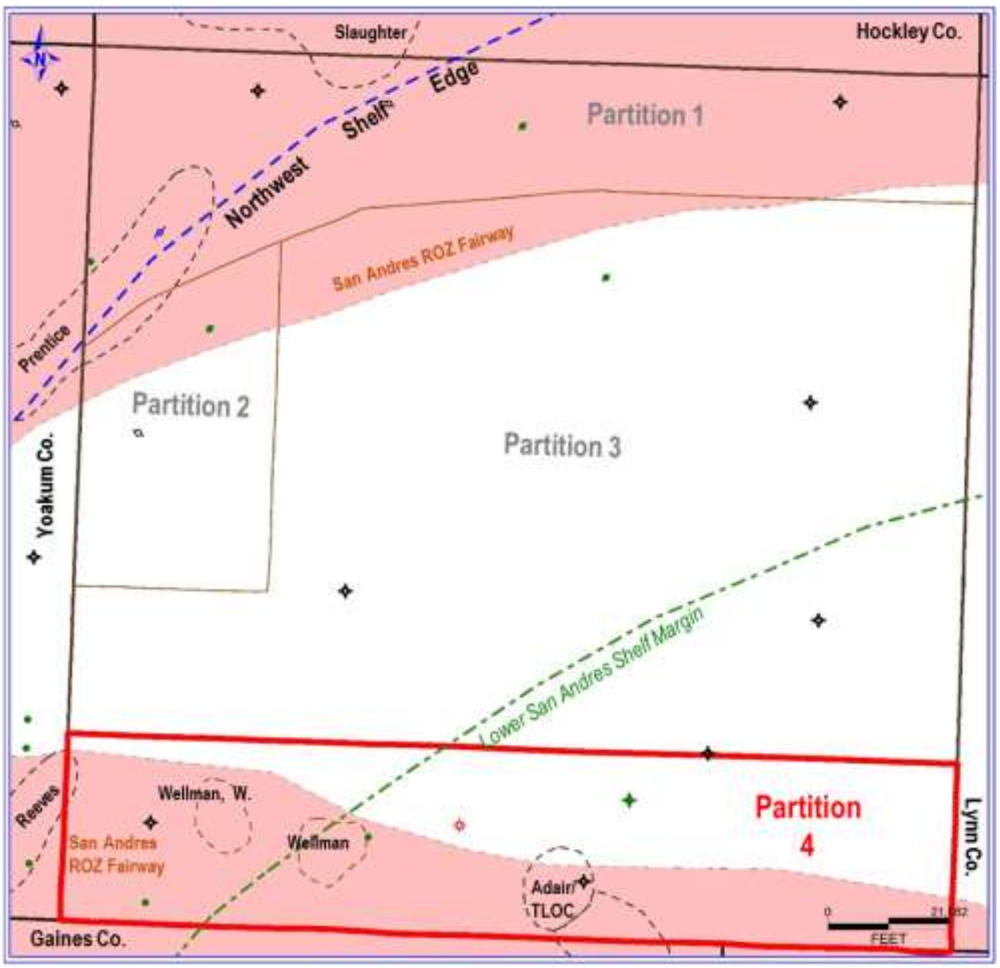
Source: Advanced Resources International, 2015

7.3C.15 Partition #4. Southern Terry County

Geologic Setting

Partition#3, located in southern Terry County, covers a San Andres ROZ "fairway" area (outside the structural limits of existing oil fields) of 111,000 acres (173 mi2), Exhibit 7.3C-17. The partition excludes the Wellman and Adair/TLOC oil fields (10,800 acres). The southern portion of Partition #4 is located within the previously established San Andres ROZ "fairway" boundaries, in the Midland Basin portion of the larger Permian Basin.

Exhibit 7.3C-17 San Andres ROZ "Fairway" Partition #4, Terry County



JAF2015_060.PPT

Source: Advanced Resources International and Melzer Consulting, 2015.

The San Andres ROZ “fairway” reservoir interval in Partition #4 of Terry County has a net thickness that ranges from 140 to 250 feet, within a gross interval of 340 feet. The ROZ interval has a porosity of 9% to 15% and holds an oil saturation that ranges from below 20% to above 30%. Oil saturation for the study wells in Partition #4 was calculated using Archie parameters: ‘m’ = 2.3; ‘n’ = 2.3; ‘a’ = 1; Rw = 0.045 – 0.05 ohm-m.

7.3C.16 Analytical ROZ Reservoir Units

A series of five well log-based reservoir data sets plus working level cross-sections were used to further divide the San Andres ROZ “fairway” resource in Partition #4 of Terry County into four analytical ROZ “fairway” reservoir units, as set forth below:

- A “higher quality” (HQ) ROZ #1 (Upper ROZ) interval
- A “lower quality” (LQ) ROZ #1 (Upper ROZ) interval
- A “higher quality” (HQ) ROZ #2 (Lower ROZ) interval
- A “lower quality” (LQ) ROZ #2 (Lower ROZ) interval

A “higher quality” analytical ROZ “fairway” reservoir unit has an average porosity greater than 8% and an average oil saturation greater than 25% for its net pay. A “lower quality” analytical ROZ “fairway” reservoir unit has an average porosity less than 8% and/or an average oil saturation less than 25% for its net pay.

A major purpose of the separation of the ROZ “fairway” resource into quality-based analytical reservoir units is to help establish the geological settings where: (1) the ROZ interval may have potential for commercial oil recovery with by-product storage of CO_2, and (2) where the ROZ interval may serve primarily as a location for storage of CO_2 with by-product production of oil.

The volumetric reservoir properties for the four analytical San Andres ROZ “fairway” reservoir units of Partition #4 of Terry County are provided on Exhibit 7.3C-18.

Exhibit 7.3C-18 Average San Andres ROZ "Fairway" Reservoir Properties: Partition #4, Terry County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Gross Thickness (ft)	163	184	155	191
Net Pay (ft)	127	106	137	94
Avg. Porosity (fraction)	0.092	0.122	0.147	0.121
Avg. Oil Saturation (fraction)	0.32	0.16	0.32	0.15
Avg. Formation Volume Factor	1.28	1.28	1.28	1.28
OIP (B/AF, for net pay)	178	118	285	110

Source: Advanced Resources International, 2015

7.3C.17 ROZ Oil In-Place

The San Andres ROZ "fairway" in Partition #4 of Terry County contains 3.93 billion barrels of oil in-place, Exhibit 7.3C-19. A little over half of the ROZ oil in-place (2.08 billion barrels) meets the "higher" ROZ resource quality criteria, thus offering the potential for commercial oil recovery with by-product storage of CO_2. The remainder of the ROZ oil in-place of 1.85 billion barrels meets the "lower" resource quality criteria, offering pore space for the storage of CO_2 with by-product production of oil.

Exhibit 7.3C-19 San Andres ROZ "Fairway" Oil In-Place: Partition #4, Terry County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Oil In-Place (B/Acre)	22,610	12,510	38,040	10,340
Area Extent (Acres)	21,000	90,000	41,000	70,000
Oil In-Place (Billion Barrels)	0.48	1.13	1.60	0.72

Source: Advanced Resources International, 2015

7.3D Dawson County

Geographic and Geologic Setting

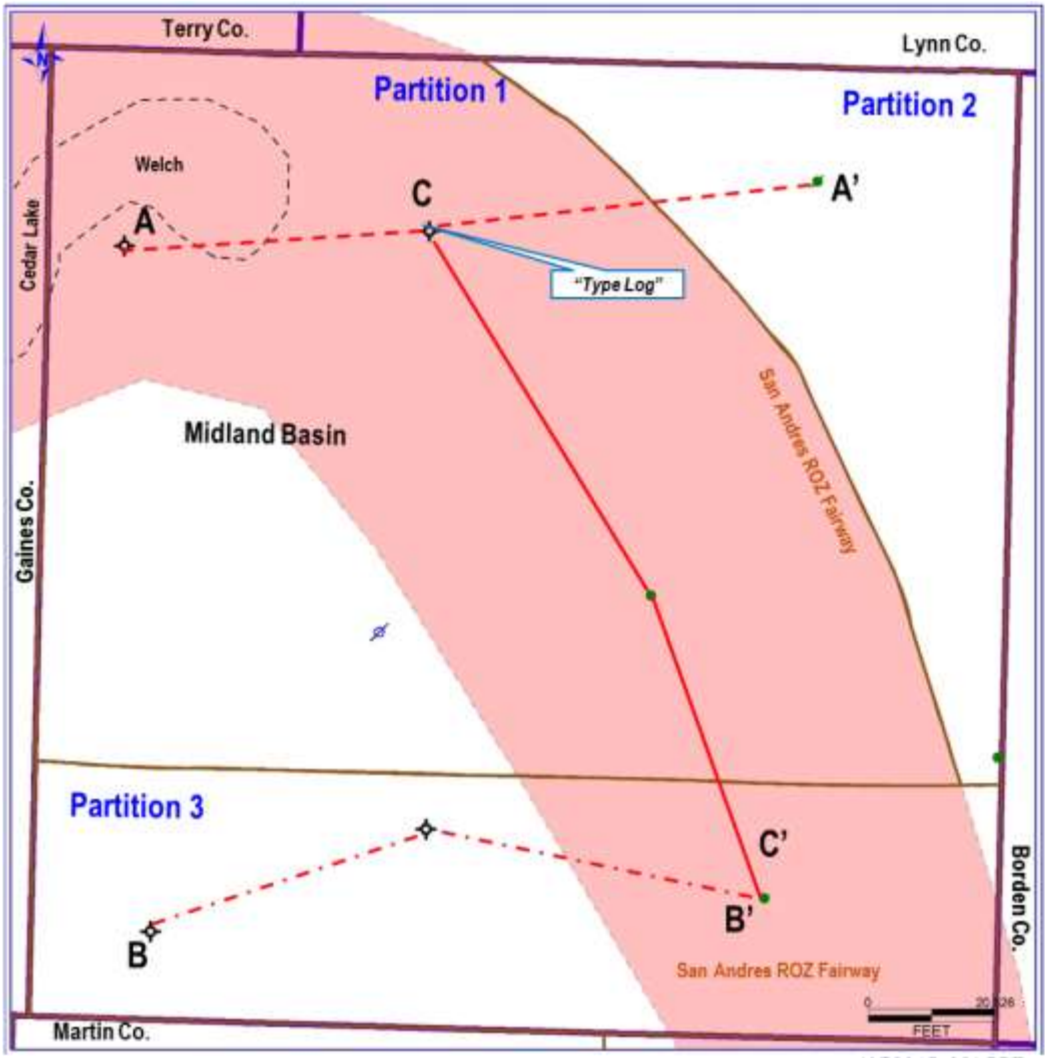
Dawson County, Texas covers a 577,700 acre (903 mi^2) area in the eastern portion of the Permian Basin. The county is located within the southward prograding Middle San Andres shelf margins of the Midland Basin.

Dawson County contains the large Welch and Cedar Lake (San Andres) oil fields in the northwest corner of the county. The ROZ resource below these San Andres oil fields has been excluded from the resource assessment of the San Andres ROZ “fairway” in Dawson County.

Based on the mapped boundary of the San Andres ROZ “fairway”, the central portion of Dawson County resides within the previously established ROZ “fairway” boundary.

The Dawson County map, Exhibit 7.3D-1, shows: (1) the location of the 9 study wells; (2) the three ROZ “fairway” partitions; (3) the boundaries of the previously established ROZ “fairway”; and (4) the extent of the Middle San Andres shelf margin. The map also shows the locations of the major San Andres oil fields excluded from the San Andres ROZ “fairway” resource assessment in Dawson County.

Exhibit 7.3D-1 Dawson County San Andres ROZ "Fairway" Geologic Partitions, Major Oil Fields and Study Well Locations



JAF2015_061.PPT

Robin Petrusak rpetrusak@adv-res.com
Vello Kuuskraa vkuuskraa@adv-res.com

Source: Advanced Resources International, 2015.

7.3D.2 Dawson County Cross-Sections

The delineation and characterization of the San Andres ROZ "fairway" interval in Dawson County has drawn on the construction of a series of working stratigraphic cross-sections. Three of these cross-sections are included in this report.

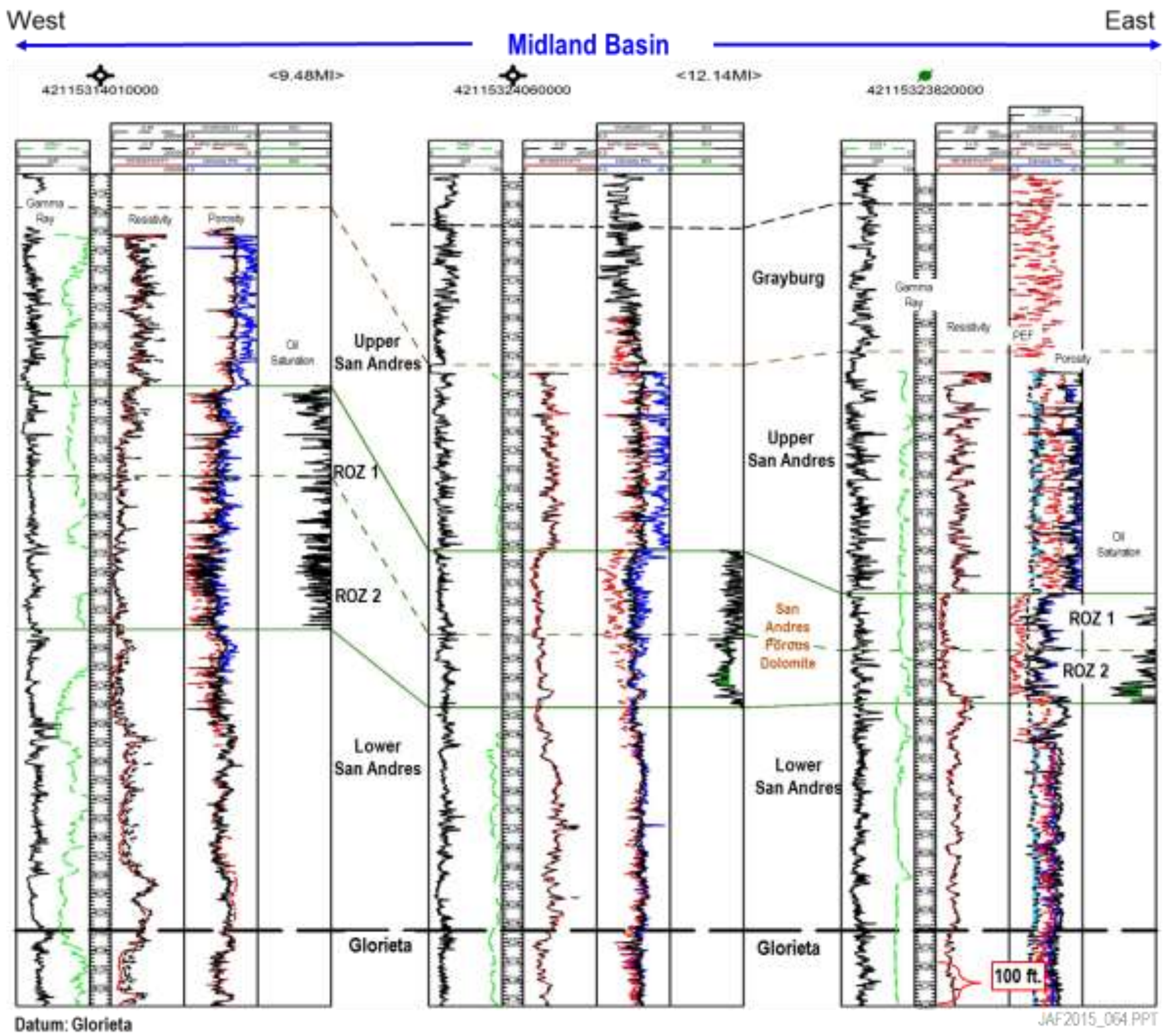
- Dawson Co. Cross-Section A-A' (Exhibit 7.3D-2) provides a W-E view of the San Andres ROZ interval through the Midland Basin in northern Dawson Co. This cross-section is hung on the Glorieta Fm. The base of the San Andres in the Dawson Co. (Midland Basin) consists of marine shale and limestone, which can be difficult to distinguish from the underlying Glorieta Formation and leads to some uncertainty in picking the top of the Glorieta on well logs. The entire section from the upper Spraberry through the San Andres ROZ was correlated to help identify the Glorieta and Clearfork formation tops.
- Dawson Co. Cross-Section B-B' (Exhibit 7.3D-3) provides a W-E view of the San Andres ROZ interval through the Midland Basin in southern Dawson Co. This cross-section is hung on the Clearfork Formation top because the top of the Glorieta Formation is uncertain.
- Dawson Co. Cross-Section C-C' (Exhibit 7.3D-4) provides a N-S view of the San Andres ROZ interval through the central portion of the mapped ROZ "fairway" in Dawson Co. This cross-section is hung on the Glorieta Fm. The base of the San Andres in the Midland Basin in Dawson Co. consists of marine shale and limestone, which can be difficult to distinguish from the underlying Glorieta Formation and leads to some uncertainty in picking the top of the Glorieta Fm on well logs.

7.3D.3 Interpretation of Dawson County Cross-Sections

For logs from existing oil fields with a Main Pay Zone, the top of the porous dolomite provides a marker for the top of the Main Pay Zone. For logs from the ROZ "fairway", the top of the San Andres porous dolomite is picked as the top of the ROZ for this resource assessment. The porous dolomite intervals informally designated as ROZ "1" and ROZ "2" are illustrated on the cross-sections.

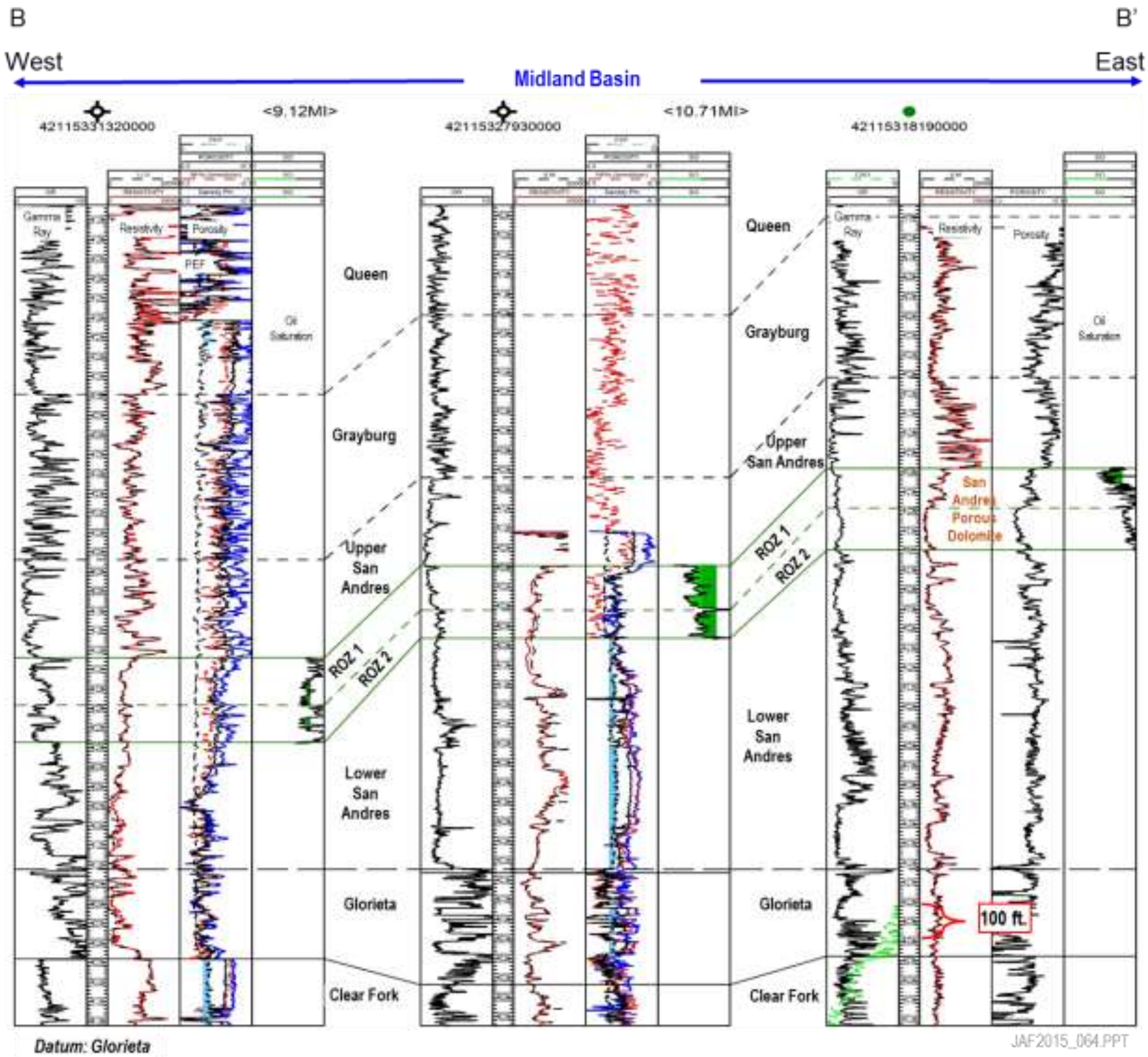
The cross-sections display gamma-ray and caliper logs in Track 1 on the left. Resistivity logs are shown in Track 2, with the deep resistivity log shown in red. Track 3 shows the porosity logs. Uncorrected neutron porosity (for limestone) is shown in red; uncorrected density porosity (for limestone) is shown in blue. The porosity curve used for the oil in-place calculation is shown in black. This porosity curve represents the "best available" porosity log for the ROZ, which may be a lithology-corrected neutron-density cross-plot porosity log, a lithology-corrected sonic porosity log, or a corrected neutron or density porosity log.

Exhibit 7.3D-2 Dawson County W-E Cross-Section A-A'



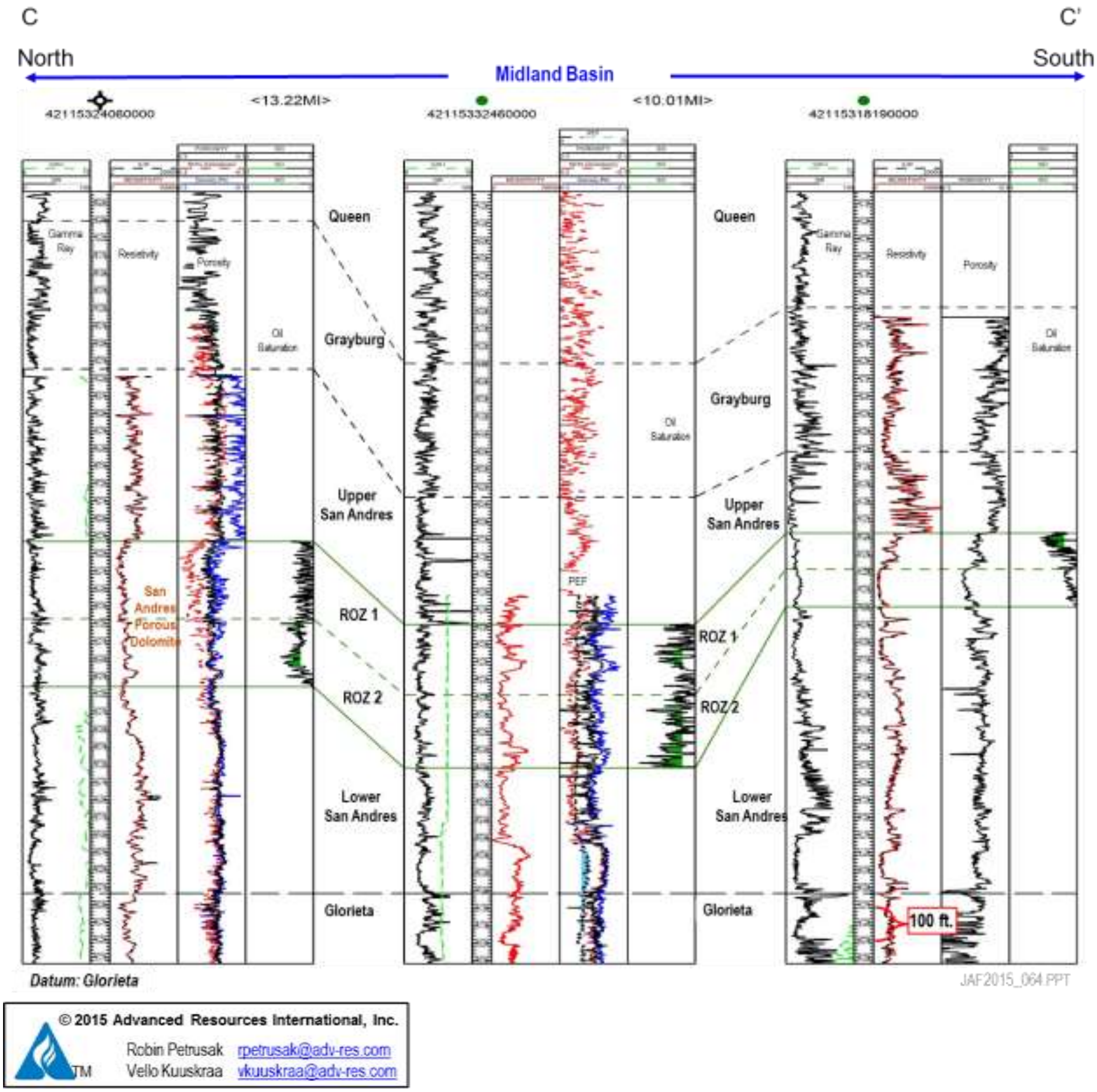
Robin Petrusak rpetrusak@adv-res.com
Vello Kuuskraa vkuuskraa@adv-res.com

Exhibit 7.3D-3 Dawson County W-E Cross-Section B-B'



Robin Petrusak rpetrusak@adv-res.com
Vello Kuuskraa vkuuskraa@adv-res.com

Exhibit 7.3D-4 Dawson County N-S Cross-Section C-C'



The photo-electric (PEF) curve, if available, is also displayed in Track 3. PEF values greater than “4” are shaded in blue. In the San Andres dolomite above the ROZ, high PEF values greater than “4” likely correspond to anhydrite. Within and below the ROZ interval, high PEF values generally indicate the presence of limestone or dolomitic limestone.

Track 4 on the right shows the calculated oil saturation. Calculated oil saturations between 25 percent and 45 percent are shaded in dark green; calculated oil saturations between 45 percent and 65 percent are shaded in light green; and oil saturation greater than 65 percent, typically present in only the Main Pay Zone, are shaded in black.

The base of the ROZ is generally picked at the point where either calculated oil saturation or apparent porosity (or both) diminish in the Lower San Andres. If a Lower San Andres limestone is prominent, the top of the limestone defines the lower boundary of the ROZ.

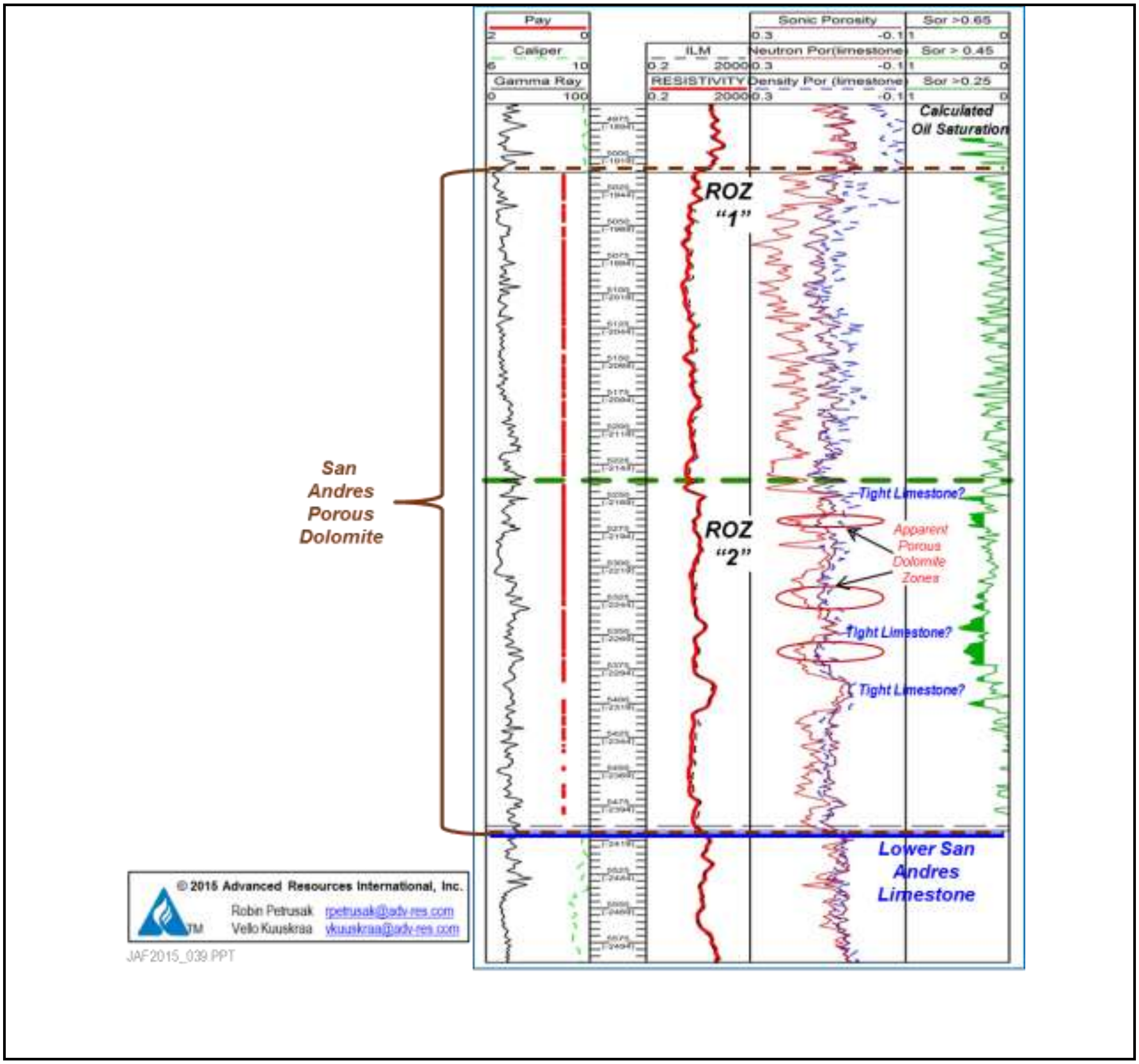
The ROZ interval and net pay in Dawson County is extensive but varies greatly - - from about 120 feet in the eastern portion of county to over 400 feet in the central and western portions of the county. Oil saturations tend to be below 25%, except in discrete areas of the county.

7.3D.4 Dawson County “Type Log”

A single “type log” was selected from the Dawson County study wells to illustrate the ROZ resource analysis undertaken for the county. Exhibit 7.3D-5 provides a close-up display of calculated porosity and oil saturation for the ROZ in the “type log.” The “type log” illustrates two distinct San Andres ROZ resource intervals - - ROZ “1” in the upper portion of the Lower San Andres porous dolomite, and ROZ “2” in the lower portion of the Lower San Andres porous dolomite.

The ROZ “1” and ROZ “2” intervals are variable across Dawson County and often appear to be shaley. ROZ “1” has more shale and thinner individual porous dolomite zones with ROZ “2” being the primary interval of interest in the “type log”. These two intervals are readily distinguished by gamma ray, porosity and resistivity log character and by the calculated oil saturation.

Exhibit 7.3D-5 Type Log For Dawson County San Andres ROZ "Fairway"



Source: Petrusak, R. and V.A. Kuuskraa, 2014, ROZ Fairway Resources of the Permian Basin: A Four-County Resource Assessment, slide no. 97, presentation prepared for Research Partnership to Secure Energy for America (RPSEA), June 25, 2014

The "type log" shows "uncorrected" neutron (red dash) and density (blue) limestone porosity. The porous dolomite in the San Andres ROZ is indicated by neutron and density logs which often indicate high porosity, even after lithology correction. Sonic porosity was used to calculate reservoir volume for this Dawson County "type log". The lithology corrected sonic porosity is shown in black. Resistivity is lower overall in ROZ "1" than ROZ "2" and porosity is higher in

ROZ “1”, particularly at the top of the ROZ “1” interval. Several low porosity, apparent limestone zones are interbedded with porous dolomite in the ROZ “2” interval. The best calculated oil saturation in ROZ “2” occurs in the porous zones between the limestone intervals. The Lower San Andres limestone forms the base for ROZ “2”.

The oil saturation for the type log ROZ was calculated using the following Archie parameters - - ‘m’ of 2.3 ‘n’ of 2.3, ‘a’ of 1, and formation water resistivity (Rw) of 0.05 ohm-m. A porosity cut-off of 6 percent was applied to define net pay in the ROZ. Intervals identified as ROZ pay are shown by the red “pay” flag in Track 1 of Exhibit 7.3D-5.

For ROZ “1”, the average porosity of net pay is 11.5% and average oil saturation of net pay is 14%. As discussed in Section 7.3 of the report, the ROZ “1” resource in the “type log” is characterized as “lower quality”. For ROZ “2”, the average porosity of net pay is 10.1% and average oil saturation is 21%. Consequently, the ROZ “2” resource in the “type log” is also characterized as “lower quality.”

7.3D.5 Partitioning the Dawson County ROZ “Fairway” Resource

The ROZ “fairway” in Dawson County is partitioned into three distinct areas, as illustrated in Exhibit 7.3D-6. Individual ROZ “fairway” resource assessments were undertaken for each of the three partitioned areas. The definition of the partitions was guided by current structure and prominent features of the Permian Basin within the Dawson County San Andres ROZ “fairway” study area.

- Partition #1. Covers a 332,000 acre (519 mi^2) area of central Dawson County. The area underneath the Welch and Cedar Lake oil fields (15,700 acres) has been excluded from the resource assessment area for Partition #1.
- Partition #2. Covers a 97,000 acre (151 mi^2) area of northeastern Dawson County.
- Partition #3. Covers a 133,000 acre (208 mi^2) area of southern Dawson County.

Dawson County covers a 577,700 acre (903 mi^2) area of the Permian Basin. A total of 15,700 acres (25 mi^2) under the structural closure of existing San Andres oil fields has been excluded, leaving a remaining ROZ assessment area of 562,000 acres (878 mi^2), Exhibit 7.3D-6.

Exhibit 7.3D-6 Dawson County ROZ "Fairway" Partitions

Partition	Total Area	Excluded Area	Assessment Area
	(Acres)	(Acres)	(Acres)
#1	347,700	15,700	332,000
#2	97,000	-	97,000
#3	123,000	-	133,000
Total	567,700	15,700	562,000

Source: Advanced Resources International, 2015.

7.3D.6 Size and Quality of the Dawson County ROZ "Fairway" Resource

Dawson County, Texas holds 27.8 billion barrels of oil in-place in the San Andres residual oil zone (ROZ) "fairway", outside the structural closure of the existing oil fields. The oil in-place and resource quality values provided for each of the four partitions for Dawson County are shown in Exhibit 7.3D-7.

- Higher Quality ROZ "Fairway" Resources. A significant portion of the San Andres ROZ "fairway" oil in-place in Dawson County of 14.6 billion barrels has "higher quality" reservoir properties (porosity greater than 8% and oil saturation equal to or greater than 25%), offering promise of commercial development of the ROZ resource with by-product storage of CO_2.
- Lower Quality ROZ "Fairway" Resources. The remainder of the San Andres ROZ "fairway" oil in-place in Dawson County of 13.2 billion barrels has "lower quality" reservoir properties (porosity equal to or less than 8% and/or oil saturation of less than 25%), offering important volumes of pore space for storage of CO_2 with by-product oil recovery.

Exhibit 7.3D-7 Dawson County San Andres ROZ "Fairway" Resource In-Place (Billion Barrels)

Partitions	ROZ 1			ROZ 2			Total		
	Higher Quality	Lower Quality	Total	Higher Quality	Lower Quality	Total	Higher Quality	Lower Quality	Total
#1	4.58	4.86	9.44	5.23	5.43	10.66	9.81	10.29	20.10
#2	-	1.56	1.56	0.70	0.31	1.01	0.70	1.87	2.57
#3	2.14	0.61	2.75	1.96	0.39	2.35	4.10	1.00	5.10
Total	6.72	7.03	13.75	7.89	6.13	14.02	14.61	13.16	27.77

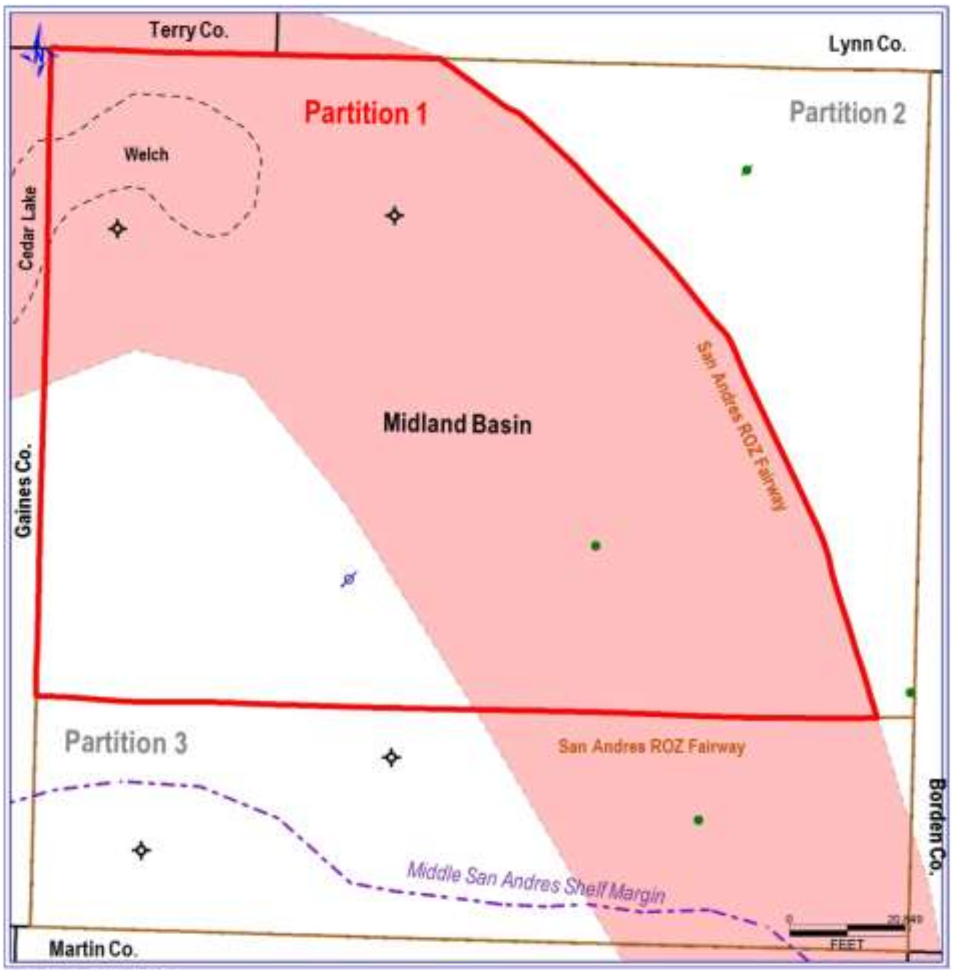
Source: Advanced Resources International, 2015.

7.3D.7 Partition #1. Central Dawson County

Geologic Setting

Partition#1, located in central Dawson County, covers a San Andres ROZ "fairway" area (outside the structural limits of existing oil fields) of 332,000 acres (519 mi^2), Exhibit 7.3D-8. The partition area excludes portions of the Cedar Lake and Welch oil fields (15,700 acres). Except for its southwestern segment, Partition #1 is located within the previously established San Andres ROZ "fairway" boundaries.

Exhibit 7.3D-8 San Andres ROZ "Fairway" Partition #1, Dawson County



JAF2015_061.PPT

Source: Advanced Resources International and Melzer Consulting, 2015.

The San Andres ROZ “fairway” reservoir interval in Partition #1 of Dawson County has a net thickness that ranges from 370 to 440 feet, within a gross interval of 480 to 780 feet. The ROZ interval has a porosity of 10 % to 13 % and holds an oil saturation that ranges from below 15 % to above 25%. Oil saturation for the study wells in Partition #1 was calculated using Archie parameters: ‘m’ = 2.3; ‘n’ = 2.3 – 3.0; ‘a’ = 1; Rw = 0.05 ohm-m.

7.3D.8 Analytical ROZ Reservoir Units

A series of four well log-based reservoir data sets plus working level cross-sections were used to further divide the San Andres ROZ “fairway” resource in Partition #1 of Dawson County into four analytical ROZ “fairway” reservoir units, as set forth below:

- A “higher quality” (HQ) ROZ #1 (Upper ROZ) interval
- A “lower quality” (LQ) ROZ #1 (Upper ROZ) interval
- A “higher quality” (HQ) ROZ #2 (Lower ROZ) interval
- A “lower quality” (LQ) ROZ #2 (Lower ROZ) interval

A “higher quality” analytical ROZ “fairway” reservoir unit has an average porosity greater than 8% and an average oil saturation greater than 25% for its net pay. A “lower quality” analytical ROZ “fairway” reservoir unit has an average porosity less than 8% and/or an average oil saturation less than 25% for its net pay.

A major purpose of the separation of the ROZ “fairway” resource into quality-based analytical reservoir units is to help establish the geological settings where: (1) the ROZ interval may have potential for commercial oil recovery with by-product storage of CO_2, and (2) where the ROZ interval may serve primarily as a location for storage of CO_2 with by-product production of oil.

The volumetric reservoir properties for the four analytical San Andres ROZ “fairway” reservoir units of Partition #1 of Dawson County are provided on Exhibit 7.3D-9.

Exhibit 7.3D-9 Average San Andres ROZ "Fairway" Reservoir Properties: Partition #1, Dawson County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Gross Thickness (ft)	316	281	238	330
Net Pay (ft)	242	198	188	183
Avg. Porosity (fraction)	0.127	0.108	0.128	0.131
Avg. Oil Saturation (fraction)	0.30	0.15	0.32	0.17
Avg. Formation Volume Factor	1.28	1.28	1.28	1.28
OIP (B/AF, for net pay)	231	98	248	135

Source: Advanced Resources International, 2015

7.3D.9 ROZ Oil In-Place

The San Andres ROZ "fairway" in Partition #1 of Dawson County contains 20.10 billion barrels of oil in-place, Exhibit 7.3D-10. About half of the ROZ oil in-place of 9.81 billion barrels meets the "higher" ROZ resource quality criteria, thus offering the potential for commercial oil recovery with by-product storage of CO_2. The remainder of the ROZ oil in-place of 10.29 billion barrels meets the "lower" resource quality criteria, thus offering pore space for the storage of CO_2 with by-product production of oil.

Exhibit 7.3D-10 San Andres ROZ "Fairway" Oil In-Place: Partition #1, Dawson County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Oil In-Place (B/Acre)	55,900	19,400	46,620	24,700
Area Extent (Acres)	82,000	250,000	112,000	220,000
Oil In-Place (Billion Barrels)	4.58	4.86	5.23	5.43

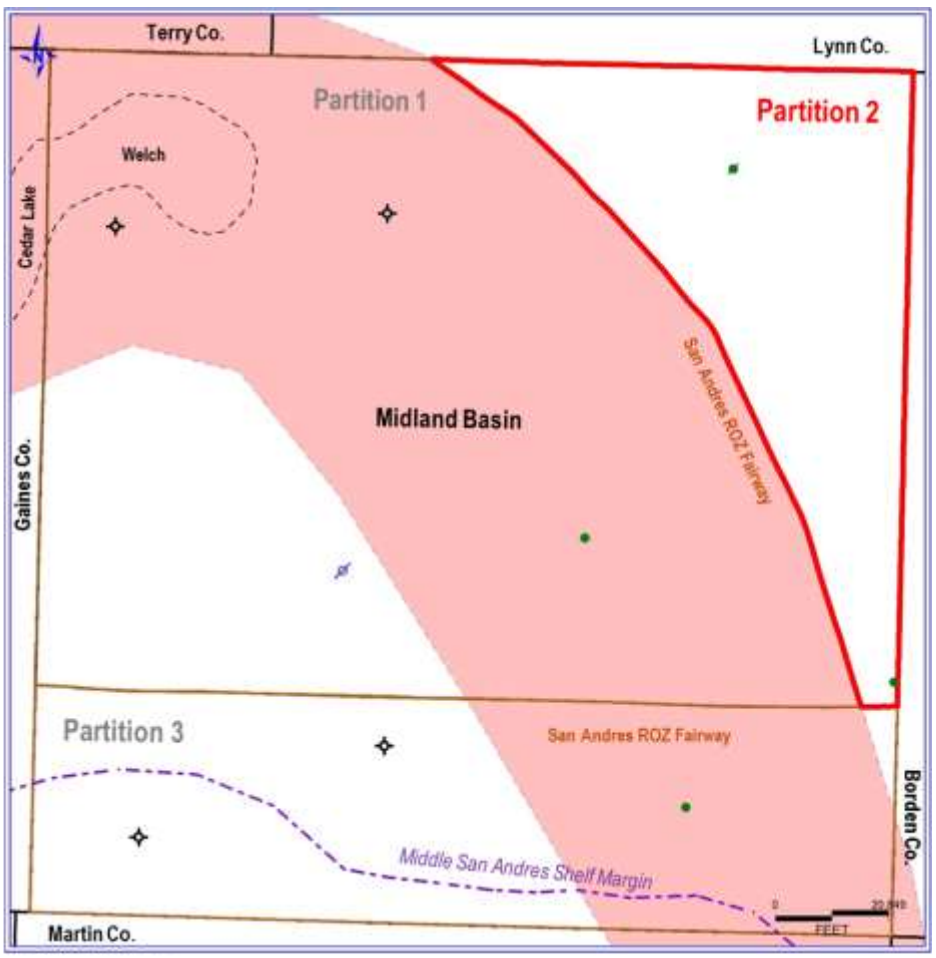
Source: Advanced Resources International, 2015

7.3D.10 Partition #2. Northeastern Dawson County

Geologic Setting

Partition#2, located in northwest Dawson County, covers a San Andres ROZ "fairway" area (outside the structural limits of existing oil fields) of 97,000 acres (152 mi^2), Exhibit 7.3D-11. The partition area does not contain any significant oil fields. Partition #2 is located outside the previously established San Andres ROZ "fairway" boundaries, in the Midland Basin of the larger Permian Basin.

Exhibit 7.3D-11 San Andres ROZ "Fairway" Partition #2, Dawson County



JAF2015_061.PPT

Source: Advanced Resources International and Melzer Consulting, 2015.

The San Andres ROZ “fairway” reservoir interval in Partition #2 of Dawson County has a net thickness that ranges from 110 to 140 feet, within a gross interval of 256 to 270 feet. The ROZ interval has a porosity of 10 % to 16% and holds a residual oil saturation that ranges from 15% to over 35%. Oil saturation for the study wells in Partition #2 was calculated using Archie parameters: ‘m’ = 2.3; ‘n’ = 2.3; ‘a’ = 1; Rw = 0.05 – 0.055 ohm-m.

7.3D.11 Analytical ROZ Reservoir Units

A series of two well log-based reservoir data sets plus working level cross-sections were used to further divide the San Andres ROZ “fairway” resource in Partition #2 of Dawson County into three analytical ROZ “fairway” reservoir units, as set forth below:

- A “lower quality” (LQ) ROZ #1 (Upper ROZ) interval
- A “higher quality” (HQ) ROZ #2 (Lower ROZ) interval
- A “lower quality” (LQ) ROZ #2 (Lower ROZ) interval

A “higher quality” analytical ROZ “fairway” reservoir unit has an average porosity greater than 8% and an average oil saturation greater than 25% for its net pay. A “lower quality” analytical ROZ “fairway” reservoir unit has an average porosity less than 8% and/or an average oil saturation less than 25% for its net pay.

A major purpose of the separation of the ROZ “fairway” resource into quality-based analytical reservoir units is to help establish the geological settings where: (1) the ROZ interval may have potential for commercial oil recovery with by-product storage of CO_2, and (2) where the ROZ interval may serve primarily as a location for storage of CO_2 with by-product production of oil.

The volumetric reservoir properties for the three analytical San Andres ROZ “fairway” reservoir units of Partition #1 of Dawson County are provided on Exhibit 7.3D-12.

Exhibit 7.3D-12 Average San Andres ROZ "Fairway" Reservoir Properties: Partition #2, Dawson County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Gross Thickness (ft)	-	249	118	199
Net Pay (ft)	-	139	42	68
Avg. Porosity (fraction)	-	0.132	0.156	0.101
Avg. Oil Saturation (fraction)	-	0.15	0.37	0.15
Avg. Formation Volume Factor	-	1.28	1.28	1.28
OIP (B/AF, for net pay)	-	116	350	92

Source: Advanced Resources International, 2015

7.3D.12 ROZ Oil In-Place

The San Andres ROZ "fairway" in Partition #2 of Dawson County contains 2.57 billion barrels of oil in-place, Exhibit 7.3D-13. Only a modest portion of the ROZ oil in-place of 0.70 billion barrels meets the "higher" ROZ resource quality criteria, thus offering the potential for commercial oil recovery with by-product storage of CO_2. The remainder of the ROZ oil in-place of 1.87 billion barrels meets the "lower" resource quality criteria, offering pore space for the storage of CO_2 with by-product production of oil.

Exhibit 7.3D-13 San Andres ROZ "Fairway" Oil In-Place: Partition #2, Dawson County

	ROZ 1		ROZ 2	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Oil In-Place (B/Acre)	-	16,120	14,700	6,260
Area Extent (Acres)	-	97,000	48,000	49,000
Oil In-Place (Billion Barrels)	-	1.56	0.70	0.31

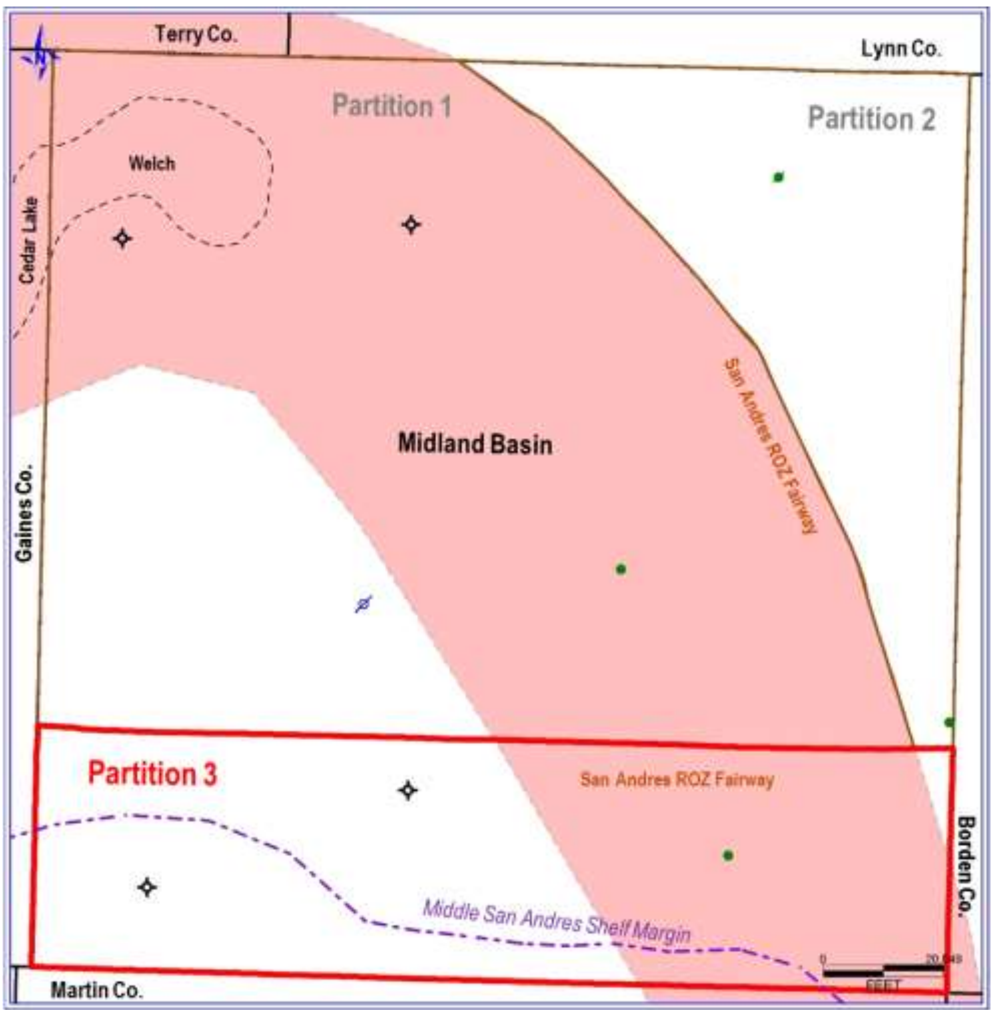
Source: Advanced Resources International, 2015

7.3D.13 Partition #3. Southern Dawson County

Geologic Setting

Partition#3, located in southern Dawson County, covers a San Andres ROZ "fairway" area (outside the structural limits of existing oil fields) of 113,000 acres (208 mi^2), Exhibit 7.3D-14. The partition area does not contain any major San Andres oil fields. The eastern portion of Partition #3 is located within the previously established San Andres ROZ "fairway" boundaries, within the Middle San Andres Shelf Margin of the Permian Basin.

Exhibit 7.3D-14 San Andres ROZ "Fairway" Partition #3, Dawson County



Robin Petrusak rpetrusak@adv-res.com
Vello Kuuskraa vkuuskraa@adv-res.com

Source: Advanced Resources International and Melzer Consulting, 2015.

The San Andres ROZ “fairway” reservoir interval in Partition #3 of Dawson County has a net thickness that ranges from 180 to 210 feet, within a gross interval of 190 to 270 feet. The ROZ interval has a porosity of 10 % to 15 % and holds an oil saturation that ranges from below 15 % to above 35 %. Oil saturation for the study wells in Partition #2 was calculated using Archie parameters: ‘m’ = 2.3; ‘n’ = 2.3; ‘a’ = 1; Rw = 0.055 – 0.06 ohm-m.

7.3D.14 Analytical ROZ Reservoir Units

A series of three well log-based reservoir data sets plus working level cross-sections were used to further divide the San Andres ROZ “fairway” resource in Partition #3 of Dawson County into four analytical ROZ “fairway” reservoir units, as set forth below:

- A “higher quality” (HQ) ROZ #1 (Upper ROZ) interval
- A “lower quality” (LQ) ROZ #1 (Upper ROZ) interval
- A “higher quality” (HQ) ROZ #2 (Lower ROZ) interval
- A “lower quality” (LQ) ROZ #2 (Lower ROZ) interval

A “higher quality” analytical ROZ “fairway” reservoir unit has an average porosity greater than 8% and an average oil saturation greater than 25% for its net pay. A “lower quality” analytical ROZ “fairway” reservoir unit has an average porosity less than 8% and/or an average oil saturation less than 25% for its net pay.

A major purpose of the separation of the ROZ “fairway” resource into quality-based analytical reservoir units is to help establish the geological settings where: (1) the ROZ interval may have potential for commercial oil recovery with by-product storage of CO_2, and (2) where the ROZ interval may serve primarily as a location for storage of CO_2 with by-product production of oil.

The volumetric reservoir properties for the four analytical San Andres ROZ “fairway” reservoir units of Partition #3 of Dawson County are provided on Exhibit 7.3D-15.

Exhibit 7.3D-15 Average San Andres ROZ "Fairway" Reservoir Properties: Partition #3, Dawson County

	ROZ 1		ROZ 2	
	Higher Quality	**Lower Quality**	**Higher Quality**	**Lower Quality**
Gross Thickness (ft)	108	121	108	97
Net Pay (ft)	92	113	98	85
Avg. Porosity (fraction)	0.112	0.103	0.113	0.158
Avg. Oil Saturation (fraction)	0.38	0.20	0.33	0.11
Avg. Formation Volume Factor	1.28	1.28	1.28	1.28
OIP (B/AF, for net pay)	258	125	223	105

Source: Advanced Resources International, 2015

7.3D.15 ROZ Oil In-Place

The San Andres ROZ "fairway" in Partition #3 of Dawson County contains 5.10 billion barrels of oil in-place, Exhibit 7.3D-16. The bulk of the ROZ oil in-place of 4.10 billion barrels meets the "higher" ROZ resource quality criteria, thus offering the potential for commercial oil recovery with by-product storage of CO_2. The remainder of the ROZ oil in-place of 1.00 billion barrels meets the "lower" resource quality criteria, thus offering pore space for the storage of CO_2 with by-product production of oil.

Exhibit 7.3D-16 San Andres ROZ "Fairway" Oil In-Place: Partition #3, Dawson County

	ROZ 1		ROZ 2	
	Higher Quality	**Lower Quality**	**Higher Quality**	**Lower Quality**
Oil In-Place (B/Acre)	23,740	14,120	21,850	8,920
Area Extent (Acres)	90,000	43,000	90,000	43,000
Oil In-Place (Billion Barrels)	2.14	0.61	1.96	0.39

Source: Advanced Resources International, 2015

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SubChapter 7.4 ROZ Fairway Resources of the Permian Basin: An Eight County Resource Assessment

Authors: Mrs. Robin Petrusak and Mr. Vello Kuuskraa, President; Advanced Resources International, Inc.

7.4.0 INTRODUCTION

This report transmits the results from the Advanced Resources International (ARI) study entitled "ROZ Fairway Resources of the Permian Basin: An Eight County Resource Assessment".

The study was intended to provide a significant step toward establishing a more in-depth understanding of the size, geological characteristics and viability of the San Andres ROZ resource in the Permian Basin by expanding to additional counties expected to have significant San Andres ROZ resources.

The study was conducted by Advanced Resources International for RPSEA (Research Partnership to Secure Energy for America) as part of a subcontract with the University of Texas of the Permian Basin, Center for Energy and Economic Diversification.

7.4.1 Overview of the Eight County ROZ Resource Assessment

Purpose and Objectives

The primary purpose of the study is to provide an initial estimate of the resource in-place for a portion of the San Andres ROZ “fairways” of the Permian Basin. The study is focused on an eight county area within the Texas portion of the Permian Basin, in Andrews, Martin, Winkler, Ector, Midland, Ward, Crane and Upton counties. Estimates of technically recoverable resources for this area of the Permian Basin was not planned or accomplished as part of the work effort here.

The study uses a substantial data set of logs, calibrated to core and water salinity data, to establish gross and net thickness, porosity and residual oil saturation for the San Andres ROZ interval. The study excludes the areas and potential ROZ resources below the numerous existing San Andres oil fields in this eight county area.

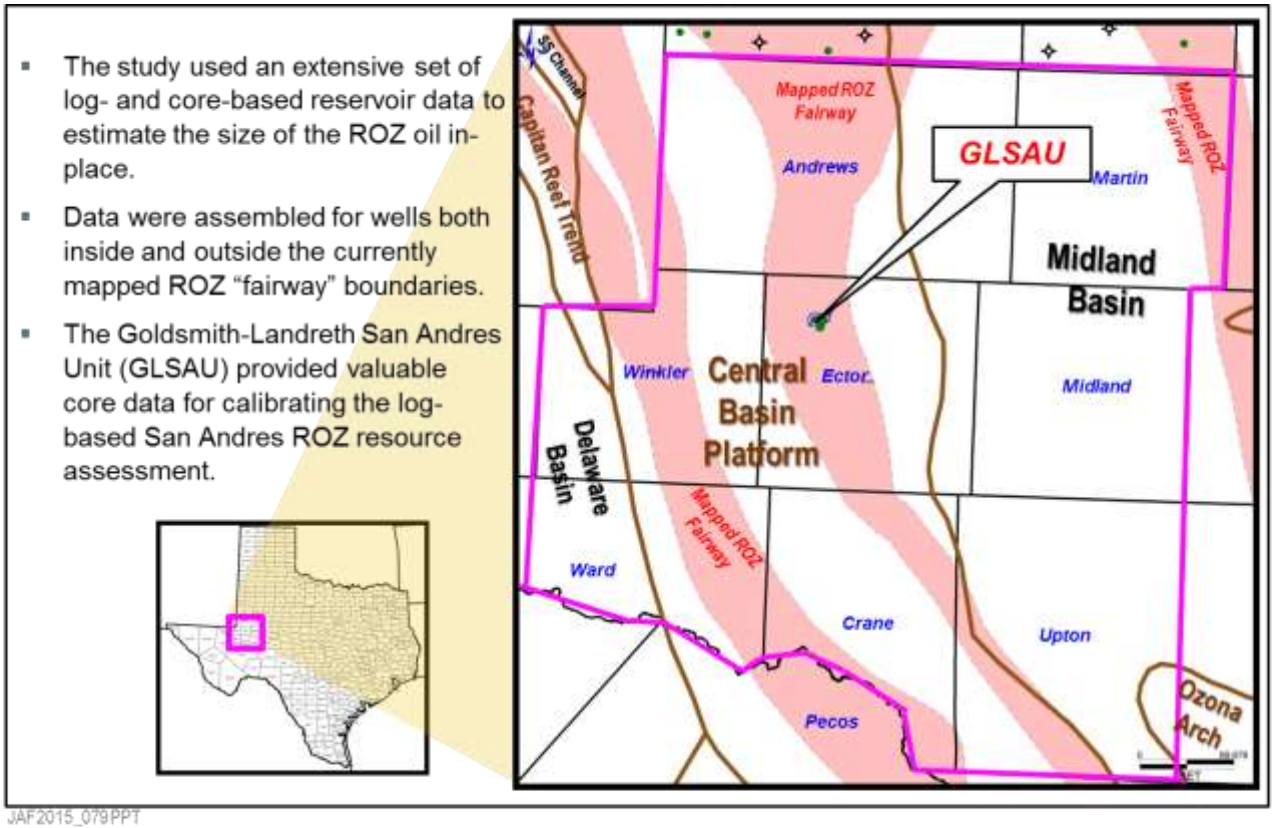
A substantial San Andres ROZ “fairway” resource has been identified in seven of the eight West Texas Permian Basin counties - - Andrews, Martin, Winkler, Ector, Ward, Crane and Upton. The ROZ resource in the eighth county, Midland, is in the Grayburg Formation, Fig. 7.4.1.

Study Methodology

The overall study methodology for estimating the resource in-place for the San Andres ROZ “fairway” includes three main components:

- Establishing the areas in these eight counties underlain by a San Andres ROZ “fairway” resource.
- Defining the San Andres ROZ gross and net interval using well logs and regional cross-sections.
- Calculating porosity and oil saturation using well logs calibrated to core analyses and regional water salinity data.

Figure 7.4.1. Eight County Study Area of Permian Basin ROZ "Fairway"



Working cross-sections were constructed using all the study wells to guide our understanding of geophysical log characteristics, thickness, apparent continuity, and other properties of the San Andres and the Grayburg ROZ.

Four of the counties (Andrews, Martin, Winkler and Ector) were treated as distinct entities and were further separated into a series of partitions corresponding to key geologic features of the San Andres ROZ, as well as data on lithology, thickness, porosity and resistivity from well logs. The three southern tier counties of Crane, Upton and Ward were treated as a single entity containing four San Andres ROZ partitions. The partitions generally align with the margins of the Central Basin Platform and Midland Basin.

Each partition is represented by a higher and a lower quality "model well" comprised of the average log-based reservoir properties for the ROZ from the study wells within each partition.

The detailed of the study methodology are further described below:

- ***Obtained digital logs for 152 study wells*** with 120 of these used in the quantitative portion of the resource assessment. The ideal log suite includes neutron, density and sonic porosity plus resistivity, gamma ray, photoelectric absorption (PEF) and caliper. A minimum acceptable log suite is sonic porosity, resistivity and gamma ray.

- ***Applied a consistent log analysis approach*** to calculate porosity, net pay and oil saturation. Variation in the quantity and quality of resources can then be attributed to actual change in the ROZ resource across the area, rather than the log analysis approach.

- ***Calibrated log analyses of the San Andres ROZ to core data from the Goldsmith-Landreth San Andres Unit*** to areas of San Andres main pay production and oil shows in the ROZ.

- ***Determined the top and base of the ROZ for each study well***, using logs calibrated to core and other benchmark data.

- ***Identified "net pay" of the San Andres ROZ***, including its porosity and oil saturation.

- ***Computed oil in-place in the San Andres ROZ for each study well***. Created "average wells" for each partition that represent the average log-calculated ROZ resource characteristics of each partition area and used these "average wells" to estimate oil in-place for each partition.

- ***Segregated the ROZ resource in each partition into "higher quality" and "lower quality" settings.***

- ***Aggregated the San Andres ROZ resource estimates for each partition to county and seven county totals.***

San Andres ROZ Characteristics across Eight County Study Area

Within the Eight County study area, a total of 2,462,400 acres (4,648 mi^2) were assessed for San Andres ROZ "fairway" resource, shown in Figure 7.4-2.

- Nearly all of the assessed area is located on the Central Basin Platform; the remaining area is located in the Midland Basin.

- The characteristics of the San Andres ROZ vary greatly depending on whether the well is located on the Central Basin Platform or is located in the Midland Basin.

- Two regional stratigraphic cross-sections (as well as numerous local cross-sections) were conducted to illustrate the variability of the San Andres ROZ "fairway" resource in the Eight County study area.

- Cross-section A-A' illustrates the San Andres ROZ from north to south along the Central Basin Platform, shown in Figure 7.4-3.

- Cross-section B-B' illustrates the San Andres ROZ from west to east across the Central Basin Platform grading into the Grayburg ROZ in the central Midland Basin, shown in Figure 7.4-4.

Figure 7.4-2. San Andres ROZ Characteristics Across Eight County Study Area

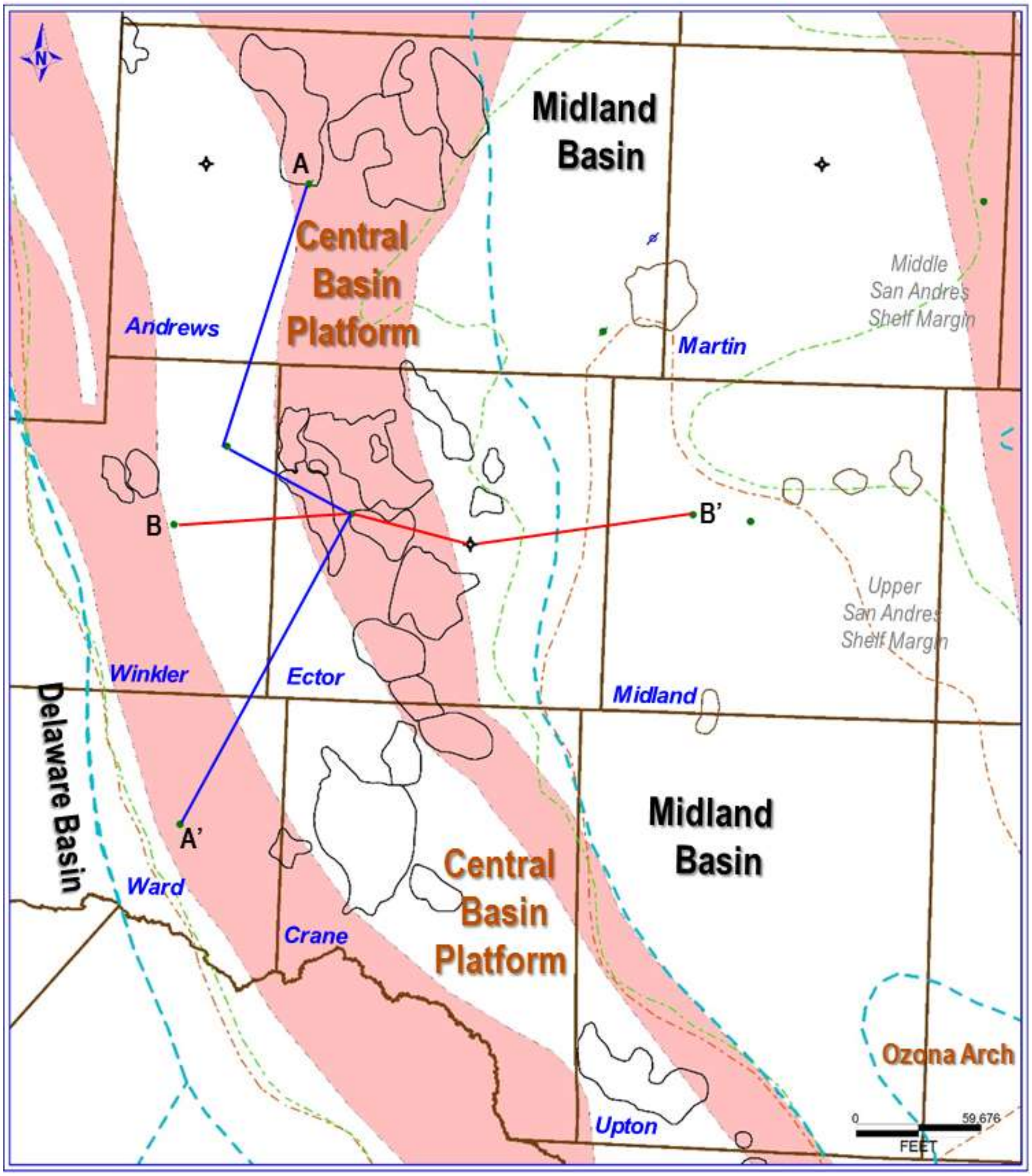


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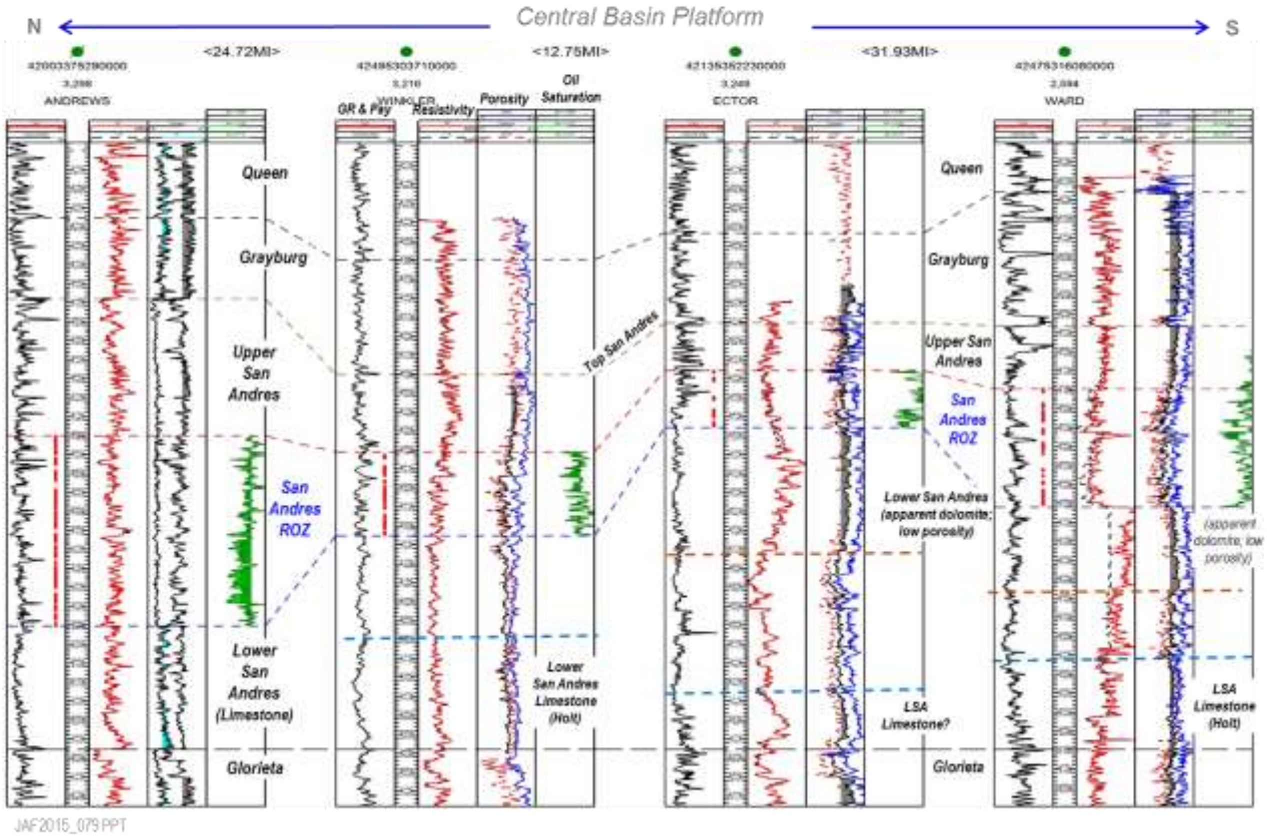
Figure 7.4-3. N-S Area Cross-Section A-A' Showing San Andres ROZ "Type Wells"

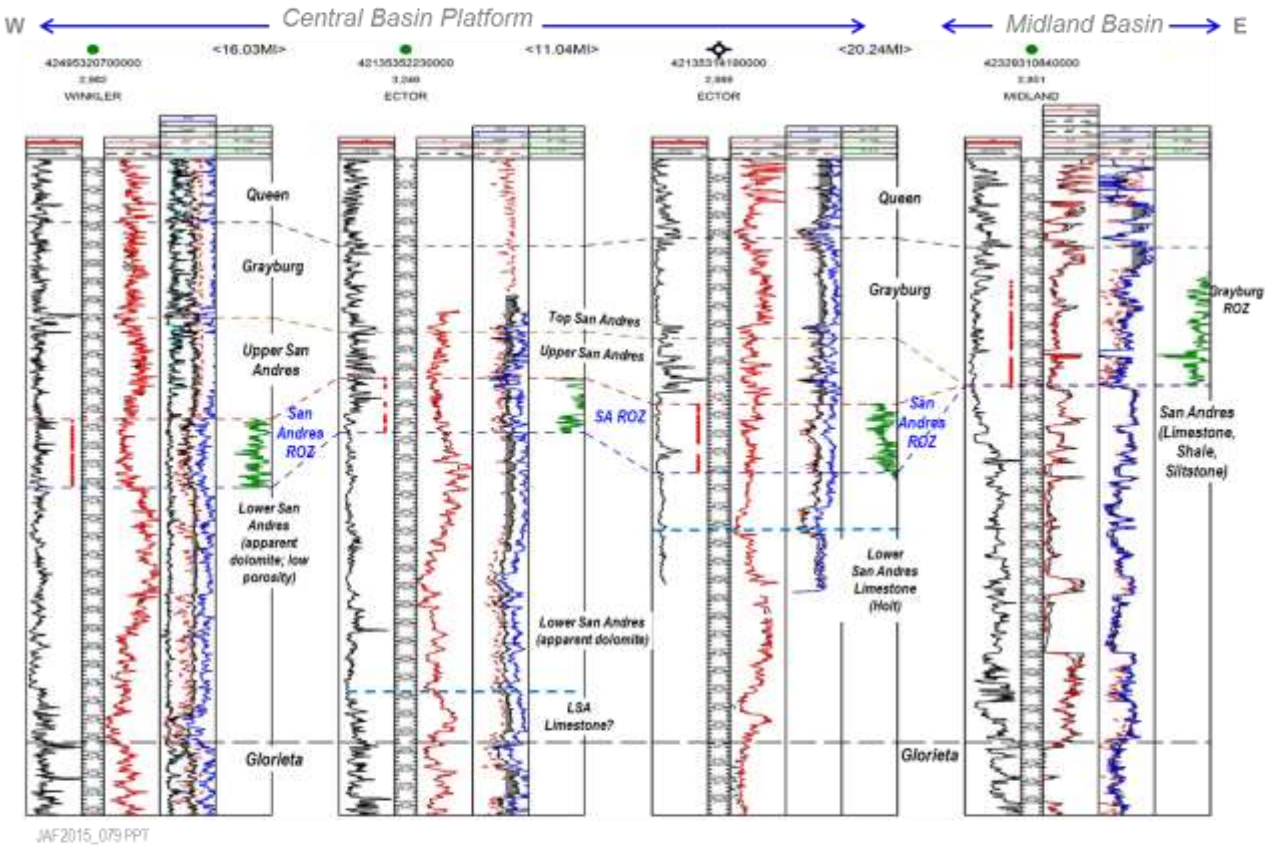


Stratigraphic Cross-Section hung on the Glorieta Formation (just below the San Andres)

Porosity logs for cross-section wells are generally density-neutron cross-plot porosity or sonic porosity. Gray shading indicates porosity less than 0.06.

Green shading in Track 4 indicates calculated So between 0.25 and 0.45. Vertical red bar in Track 1 = net pay indicator where ROZ "pay" has porosity >0.06; no Sor pay cutoff applied.

Figure 7.4-4. W-E Area Cross-Section B-B' Showing San Andres ROZ "Type Wells"



Stratigraphic Cross-Section hung on the Glorieta

Porosity logs for cross-section wells are density-neutron cross-plot porosity. Gray shading indicates porosity less than 0.06.

Green shading in Track 4 indicates calculated So between 0.25 and 0.45. Vertical red bar in Track 1 = net pay indicator where ROZ "pay" has porosity >0.06; no Sor pay cutoff applied.

Areal Coverage of the ROZ "Fairway" Resource Assessment

The ROZ study assessed a significant land area - - over 4.88 million acres (7,620 mi^2). Approximately half of the area (2.41 million acres; 3,773 mi^2), where the San Andres ROZ is absent or where the San Andres ROZ is below the structural closure of existing San Andres oil fields, was excluded.

Andrews County. The Andrews County ROZ "fairway" covers a 657,600 acre (1,028 mi^2) area, with 127,200 acres (199 mi^2) below the San Andres Fm oil fields excluded from the resource assessment. An additional 175,700 acres (275 mi^2) were excluded because the San Andres ROZ was absent. In this area a ROZ appears to exist in the Grayburg Formation. The great bulk of the western and central portions of Andrews County is underlain by higher quality ROZ resources.

Martin County. The Martin County ROZ "fairway" covers a 353,600 acre (553 mi^2) area with 6,300 acres (10 mi^2) below the San Andres Fm oil fields excluded. An additional 226,100 acres (353 mi^2) were excluded because the San Andres ROZ was absent. In this area a ROZ appears to exist in the Grayburg Formation. While much of Martin County is underlain by lower quality ROZ resources, the eastern portion of the county contains higher quality ROZ resources.

Winkler County. The Winkler County ROZ "fairway" covers a 342,800 acre (536 mi^2) area, with the western portion of the county, where the San Andres Fm is absent, excluded from the resource assessment. Much of the remainder of the ROZ acreage, particularly in the center of the county, has higher quality ROZ resource.

Ector County. The Ector County ROZ "fairway" covers a 348,300 acre (544 mi^2) area, with approximately 121,800 acres below the San Andres Fm oil fields excluded from the resource assessment. An additional 106,900 acres (167 mi^2) were excluded because the San Andres ROZ was absent. In this area, a ROZ appears to exist in the Grayburg Formation. Much of Ector County, particularly in its central area, holds higher quality ROZ "fairway" resources.

Three Southern Tier Counties. The ROZ "fairway" resource of Crane, Upton and Ward counties covers a 760,000 acre (1,188 mi^2) area. Approximately 163,000 acres below the San Andres oil fields within these three counties, as well as eastern Upton County and western Ward County, where the presence of the San Andres ROZ is uncertain, have been excluded from the resource assessment.

Midland County. The Midland County ROZ "fairway" assessment established that the San Andres ROZ was absent but contains an extensive ROZ resource in the Grayburg Formation.

After excluding the areas outside the San Andres ROZ study boundaries and the areas underneath existing major San Andres oil fields, the ROZ "fairway" study assessed 2.46 million acres (3,848 mi^2), shown in Table 7.4-1. Slightly more than half of the assessed area (1,254,100 acres; 1,960 mi^2) holds higher quality ROZ resources. Somewhat less than half of the assessed area (1,208,300 acres; 1,888 mi^2) holds lower quality ROZ resources.

Table 7.4-1. Distribution of the Eight County Land Area

County	**Total Area**	**Outside Study Boundaries**	**Below Existing Oil Fields**	**Sub-Total Area**	**Quality Area**	
					Higher	**Lower**
	(Acres)	(Acres)	(Acres)	(Acres)	(Acres)	(Acres)
Andrews	960,500	(175,700)	(127,200)	657,600	376,900	280,700
Martin	586,100	(226,100)	(6,300)	353,700	202,100	151,600
Winkler	342,800	-	-	342,800	245,200	97,600
Ector	577,000	(106,900)	(121,800)	348,300	202,900	145,400
Three Southern Tier	1,833,000	(910,000)	(163,000)	760,000	227,000	533,000
Midland	577,400	(577,400)	-	-	-	-
Total San Andres	**4,876,800**	**(1,996,100)**	**(418,300)**	**2,462,400**	**1,254,100**	**1,208,300**

Results of San Andres ROZ "Fairway" Resource Assessment

Our detailed analysis of 152 study area logs (with 120 log-based data points used in the quantitative portion of the resource assessment) identifies 79.5 billion barrels of San Andres ROZ oil in-place, Table 7.4-2.

Nearly three quarters of this San Andres ROZ resource, 58.2 billion barrels, is higher quality, with porosity greater than 8% and oil saturation greater than 25%. The remainder of the

San Andres ROZ resource, 21.2 billion barrels, is lower quality, with porosity less than 8% and oil saturation less than 25%. The ROZ "fairway" resource quality and concentrations vary widely in the eight county study area.

Table 7.4-2. Summary of San Andres "Fairway" Resources: Eight Counties of the Permian Basin

County	Higher Quality ROZ Resources (Billion Bbls)	Lower Quality ROZ Resources (Billion Bbls)	Total ROZ Resources (Billion Bbls)
Andrews	31.23	5.90	37.13
Martin	4.80	1.94	6.74
Winkler	7.98	1.49	9.47
Ector	5.55	1.40	6.95
Three Southern Tier	8.67	10.51	19.18
Total (San Andres ROZ)	**58.23**	**21.24**	**79.47**

Andrews County. The western and central areas of Andrews County, on the Central Basin Platform, contain a thick package of ROZ net pay[4], ranging from 150 to 400 feet, with favorable oil saturations of +34% in the higher quality portions of these areas. The eastern portion of Andrews County, in the Midland Basin, has appreciably lower net pay (50 to 100 feet) and lower oil saturation.

[4] Net pay cut-off of 6% for porosity; no cut-off for oil saturation.

Martin County. The western and central areas of Martin County, in the Midland Basin, holds a moderate package of ROZ net pay, on the order of 100 feet with oil saturations below 25%. The eastern area of the county, particularly within the previously defined ROZ "fairway", has thicker net pay, ranging from 120 to 170 feet, with moderate oil saturation of 30%.

Winkler County. The central and eastern areas of Winkler County, in the Central Basin Platform, contain an attractive package of ROZ net pay, generally ranging from 130 to 180 feet. In the central portion of the county, within the previously mapped ROZ "fairway", oil saturation appears to range from 35% to 40%, decreasing to the east.

Ector County. The central portion of Ector County, on the Central Basin Platform, has a widely variable ROZ net pay, ranging from 100 feet to pockets in excess of 250 feet. Oil saturations in the higher quality areas range from 30% to 35%, with porosities (for net pay) of about 10%.

Three Southern Tier Counties. The ROZ "fairway" resource of Crane, Upton and Ward counties is highly variable, ranging from 200 net feet of moderate porosity on the west to 100 net feet of lower porosity on the east. Oil saturation, tends to be lower, ranging from 25% to 30%. Much of Upton County, particularly its eastern portion, has been excluded from the resource assessment.

Midland County. The ROZ resource in Midland County is within the Grayburg Fm and is not included in the San Andres ROZ resource assessment in this report.

Considerable additional detail is provided in the five subsequent sections addressing these eight counties.

7.4.2 SUPPORTIVE DETAILS FOR THE EIGHT COUNTY ROZ RESOURCE ASSESSMENT

Geologic Setting of the Permian Basin

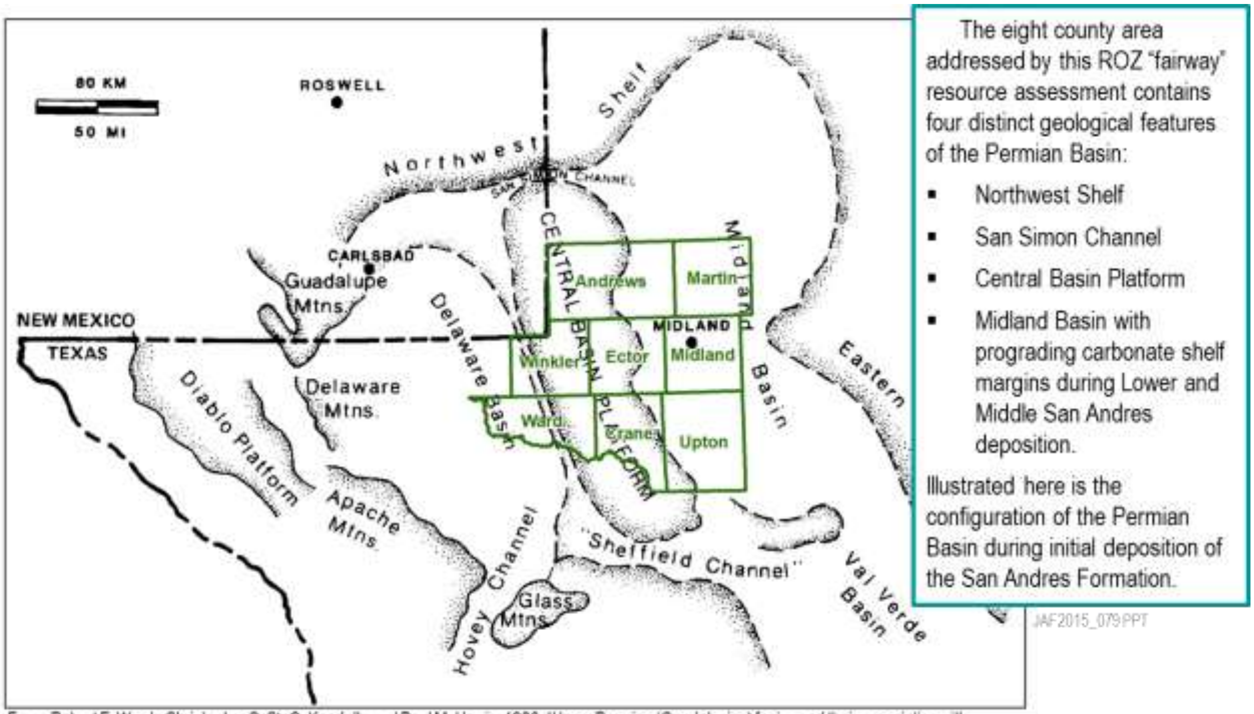
The Permian Basin, located in West Texas and East New Mexico, contains one of the world's thickest deposits of rocks (sediments) from the Permian geologic period. The basin encompasses a massive land area, 250 miles wide (east to west) and 300 miles long (north to south), shown in Figure 7.4-5.

The Permian Basin is characterized by geological and structural features that have influenced the movement and accumulation of oil. These include the following structural features:

1. Northwest Shelf and Eastern Shelf;
2. Central Basin Platform;
3. Diablo, Hovey, San Simon and Sheffield channels; and
4. Delaware, Midland and Val Verde basins, within the larger Permian Basin.

In addition, shifting marine shelf margins during deposition of the Permian Basin carbonate profoundly influenced reservoir characteristics such as porosity development, reservoir facies and thickness. These shifting shelf margins also influenced the subsequent development of regional pathways for migration of oil and water.

Figure 7.4-5. Key Permian Basin Features



From: Robert F. Ward, Christopher G. St. C. Kendall, and Paul M. Harris, 1986, "Upper Permian (Guadalupian) facies and their association with hydrocarbons; Permian Basin, West Texas and New Mexico", AAPG Bulletin, , v. 70, no. 3, p. 239-262.

Permian Basin ROZ "Fairways"

Work by Trentham, Melzer and others has established that a widely distributed oil resource exists in the ROZ "fairways" surrounding the structurally defined oil fields of the Permian Basin.[5]

Mapping by Melzer and others has identified four of these ROZ "fairways": (1) Slaughter Fairway; (2) Roswell Fairway; (3) Artesia Fairway; and (4) Capitan Fairway. These fairways merge in the Central Basin Platform portion of the Permian Basin.

The eight county ROZ resource assessments being conducted by Advanced Resources International targets the Artesia and Capitan fairways in the northern portion of the larger Permian Basin ROZ "fairway", and the potential merging of these two "fairways" with the Slaughter and Roswell fairways to the north.

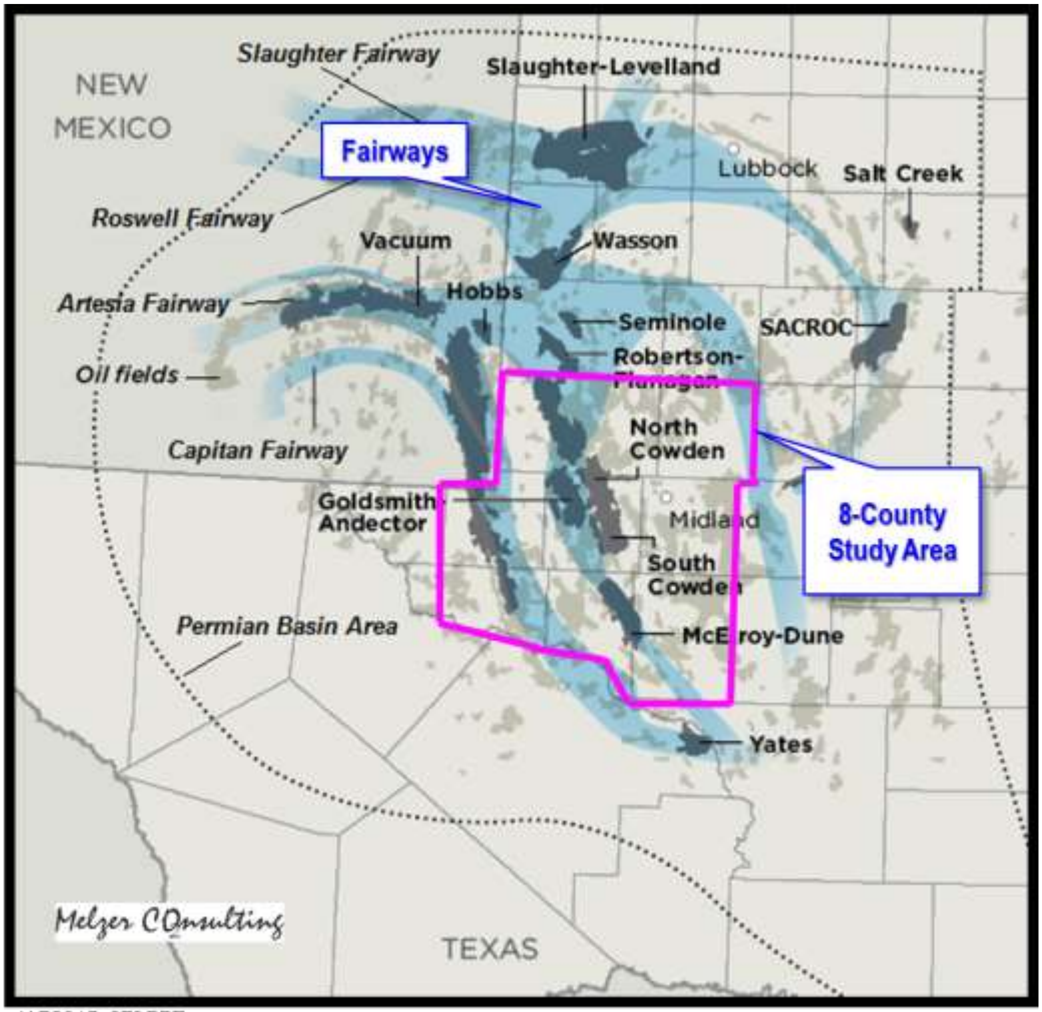
Mapping of Residual Oil Zone Fairways in the Permian Basin and Active Major CO_2 EOR Projects

The eight county ROZ "fairway" resource assessment addresses the Capitan and Artesia fairways and their merging with the Slaughter and Roswell fairways in the Central portion of the Permian Basin.

The eight county ROZ resource assessment encompasses the Central Basin Platform and Midland Basin in the southern portion of the Permian Basin, shown in Figure 7.4-6.

[5] * Robert Trentham, L. Steven Melzer, David Vance, Commercial Exploitation and the Origin of Residual Oil Zones: Developing a Case History in the Permian Basin of New Mexico and West Texas, Research Partnership to Secure Energy for America, Contract 81.089 08123-19-RPSEA, June 28, 2012.

Figure 7.4-6. Map of the Permian Basin Showing the Eight County Area.



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The primary target for the Permian Basin ROZ “fairway” resource study is the Permian-age San Andres Formation, the dominant oil producing horizon in this basin.

The San Andres Formation is comprised of platform carbonates and evaporites deposited on a broad, low-relief shelf that surrounded the Midland Basin during the middle Permian (Upper Leonardian/Guadalupian). Shelf deposits of the San Andres range from limestone wackestones of the outer shelf; grainstone shoals and banks of the shelf crest; dolomite of shallow subtidal to intertidal origin of the middle shelf; and restricted mud flats, algal deposits, and supratidal evaporites of the interior shelf.

Closing of the Midland Basin exposed the San Andres carbonate platform prior to deposition of the Grayburg during a subsequent marine transgression. The outer shelf deposits of the lower Grayburg are overlain by carbonate sands and dolomitized shallow subtidal shelf deposits of the middle Grayburg. The “shallowing upward” carbonate shelf succession of the Grayburg is capped by intertidal sediments of the upper Grayburg and supratidal and terrigenous deposits of the overlying Queen Formation.

Throughout the ROZ study area, porous reservoirs in the San Andres and Grayburg are found in multiple zones, commonly in shallow subtidal dolograinstones and dolopackstones.

Stratigraphic Chart – San Andres Formation

The San Andres Formation in the study area is 600’ to more than1,600’ thick. The San Andres Formation is underlain by the Glorieta/ San Angelo Formation and overlain by the Grayburg Formation, shown in Figure 7.4-7.

Age progression of the San Andres Formation is the result of rapid closing of the Midland Basin and prograding of the carbonate shelf southward during the time of San Andres deposition.

Thickness of the Grayburg Formation ranges from approximately 150’ to 450’. The base of the Grayburg may be identified in core by subaerial exposure features, but can be difficult to distinguish from the San Andres on well logs.

Figure 7.4-7. Stratigraphic Chart – San Andres Formation

SYSTEM		Stage	High Frequency Stratigraphic Sequence	Delaware Basin		Central Basin Platform		Midland Basin	
PERMIAN	Upper	Guadalupian	G 25 - 28	Delaware Mountain Grp.	Bell Canyon	Artesia Grp./ Capitan	Tansill	Artesia Grp.	Tansill
			G 21 - 24				Yates		Yates
			G 17 - 20				Seven Rivers		Seven Rivers
			G 13 - 16		Cherry Canyon		Queen		Queen
			G 10 - 12				Grayburg		Grayburg
			G 9			Upper San Andres		San Andres	
			G 8		Brushy Canyon	Upper San Andres	Judkins		
			G 5-7					Brushy Canyon Equiv	
			G 3-4	Cutoff		Middle San Andres	Intermediate		
			G 1-2	Bone Spring/ Cutoff		Lower San Andres	McKnight		
	Lower	Leonardian	L 7-8	Bone Spring			Holt	Lower San Andres	Holt
			L 5-6			Glorieta		Glorieta/ San Angelo	
						Clear Fork Group		Clear Fork Group/ Spraberry	
						Abo/Wichita			

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Sources: Trentham, R., 2011, Residual Oil Zones: The Long Term Future of Enhanced Oil Recovery in the Permian Basin and Elsewhere, American Association of Petroleum Geologists Search and Discovery Article #40787, posted August 15, 2011.

Ruppel, S.C. and D.G. Bebout, Competing Effects of Depositional Architecture and Diagenesis on Carbonate Reservoir Developments: Grayburg Formation, South Cowden Field, West Texas, Texas Bureau of Economic Geology, Report of Investigations No. 263, 62 pp.

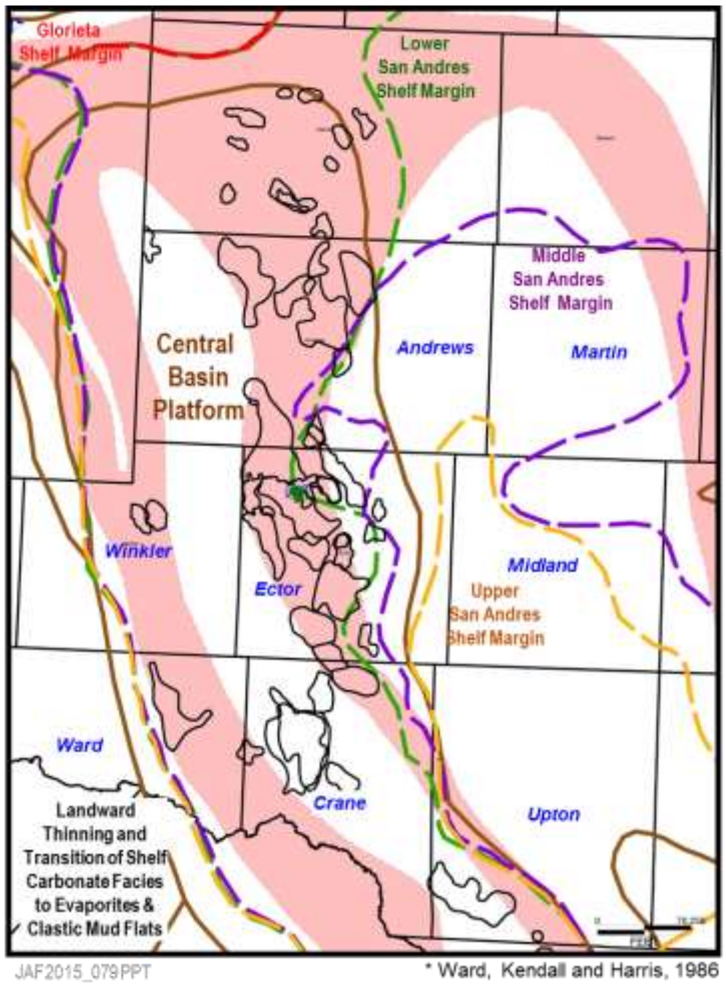
Dutton, S.P. and six others, 2004, Play Analysis and Digital Portfolio of Major Oil Reservoirs in the Permian Basin: Application and Transfer of Advanced Geological and Engineering Technologies for Incremental Production Opportunities, Final Report, 408 pp.

Prograding Shelf Margins During San Andres Deposition: Lower – Middle San Andres Oil Fields

San Andres oil fields of the Central Basin Platform (CBP) are shown in black. The Artesia ROZ “Fairway” and Middle/Lower San Andres oil fields of the CBP align with the Lower and Middle San Andres shelf margin, as shown in Figure 7.4-8.

The Capitan ROZ Fairway aligns with western margins of the San Andres shelf, where porous dolomite grain-stone, packstone and wackestone of mid and outer shelf facies are replaced by supratidal evaporites, tidal mud flats, algal deposits, and fine-grained clastic deposits of the interior shelf.

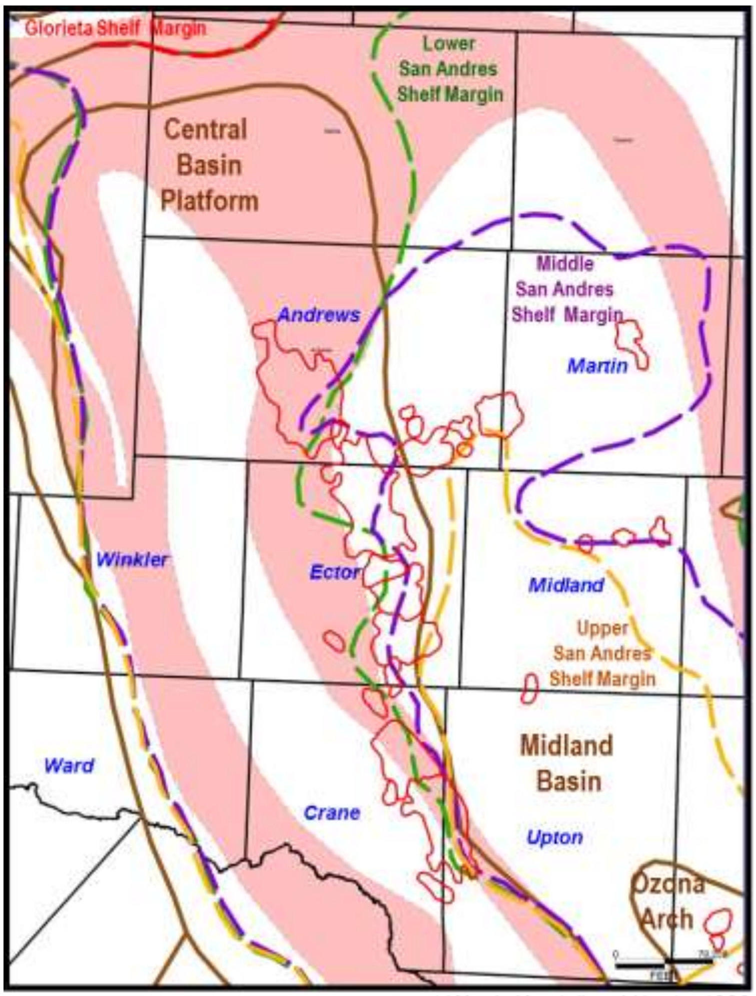
Figure 7.4-8. Map of Prograding Shelf Margins During San Andres Deposition: Lower – Middle San Andres Oil Fields



Prograding Shelf Margins During San Andres Deposition: Middle – Upper San Andres/ Grayburg Fields

Oil fields producing from the Middle to Upper San Andres and Grayburg are shifted east of the San Andres oil fields of the Central Basin Platform. This appears to be in response to contraction of the Midland Basin during the Middle and Upper San Andres and Grayburg and the margin of the carbonate shelf prograding seaward, as shown in Figure 7.4-9.

Figure 7.4-9. Prograding Shelf Margins During San Andres Deposition: Middle – Upper San Andres/ Grayburg Fields



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* Ward, Kendall and Harris, 1986

Upper San Andres/Grayburg oil fields align with the Middle and Upper San Andres Shelf Margins. Upper San Andres/Grayburg oil fields appear to have an ROZ that is distinct from the mapped ROZ fairways shown here.

CO_2 Enhanced Oil Recovery: ROZs Below Existing Fields

Prior work has established that in addition to the main pay zone (MPZ), a residual oil zone (ROZ) exists below many of the San Andres Formation oil fields in the Permian Basin.[6,7] To date, several of the major basin operators have begun to test and develop this ROZ resource in oilfields such as Goldsmith, Seminole and Wasson, among others, Table 7.4-3.

Table 7.4-3. Permian Basin San Andres Oil Fields with Publically Reported ROZ CO_2 EOR Projects

Permian Basin ROZ Projects					OGJ 2014 EOR Survey			
Operator	Field	State	County	Depth	Start Date	Acreage Under Development	Oil Production Total (B/D)	Oil Production Enhanced (B/D)
1. Publically Available Information								
Hess	Seminole Unit-ROZ Phase 1	TX	Gaines	5,500'	7/96	500	1,200	1,200
Hess	Seminole Unit-ROZ Phase 2	TX	Gaines	5,500'	4/04	480	1,800	1,800
Hess	Seminole Unit-ROZ Stage 1-3	TX	Gaines	5,500'	10/07	2,320	3,500	3,500
Kinder Morgan	Tall Cotton Phase 1	TX	Gaines	5,350'	1/15	180	-	-
Kinder Morgan	Tall Cotton Phase 2	TX	Gaines	5,350'	1/15	3,880	-	-

[6] Koperna, G.J. and Kuuskraa, V.A., (2006), “Assessing Technical and Economic Recovery of Oil Resources in Residual Oil Zones: Permian Basin,” U.S. Department of Energy, Advanced Resources International, February 2006.

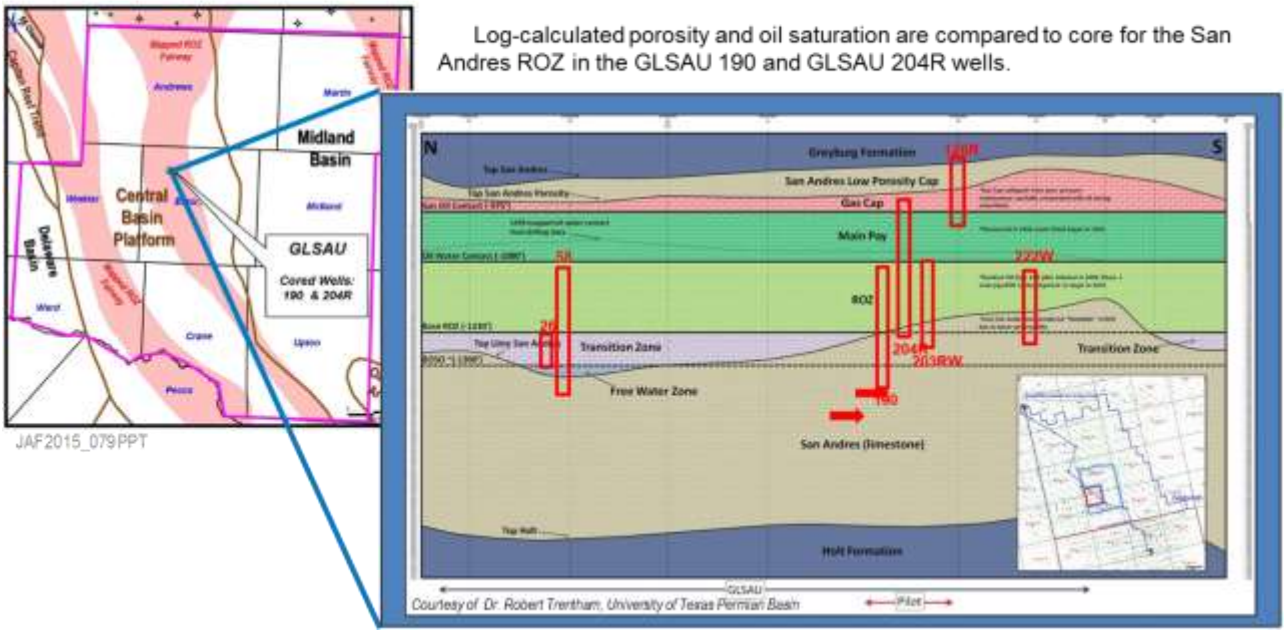
[7] L. S. Melzer, Melzer Consulting, Residual Oil Zones in the Permian Basin: Exploiting Mother Nature’s Waterfloods and Rethinking the Concept of Transition Zones”, 08123-19, RPSEA Onshore Production Conference: Technological Keys to Enhance Production Operations, April 10, 2012, Midland, Texas

Kinder Morgan	GLSA Unit "Study Area"	TX	Gaines	5,350'	9/09	360	250	250
						Total	**6,750**	**6,750**

Comparing the ROZ Resource Assessment Approach to an Actual ROZ: Goldsmith-Landreth San Andres Unit

The Goldsmith-Landreth San Andres Unit (GLSAU) provided valuable core data for calibrating the log-based ROZ resource assessment, shown in Figure 7.4-10.

Figure 7.4-10. Goldsmith-Landreth San Andres Unit

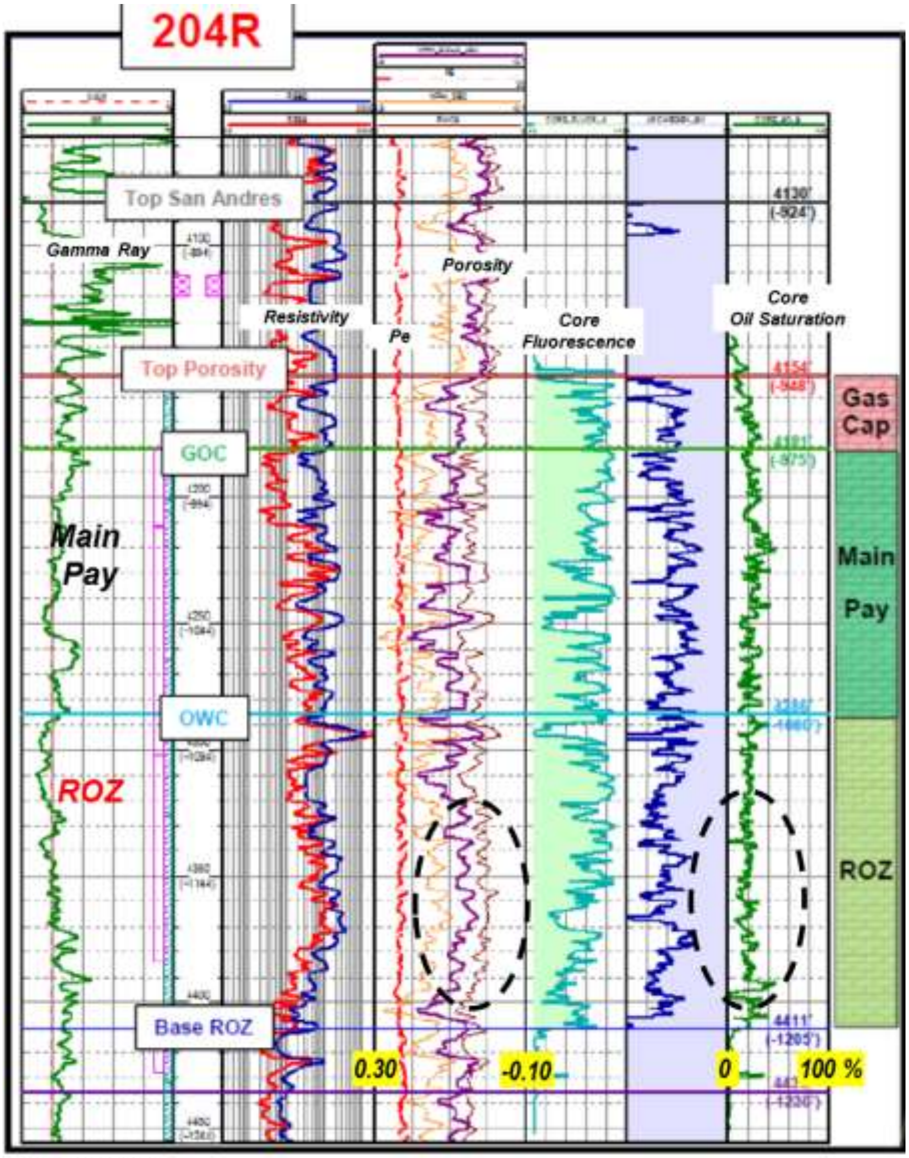


Type Log for GLSAU San Andres ROZ CO2 Injection Pilot*

Note lower porosity and lower core oil saturation in ROZ compared to the Main Pay. Limestone content and apparent shaliness in the San Andres dolostones increase with depth in lower ROZ. A subtle porosity reduction and lithology change is observed on logs from the top of the ROZ to the base of the ROZ, shown in Figure 7.4-11.

- Main Pay Thickness = 135 ft. (from top porosity to OWC)
- ROZ Thickness = 125 ft. (from top OWC to Base ROZ)

Figure 7.4-11. Type Log for GLSAU San Andres ROZ CO2 Injection Pilot*



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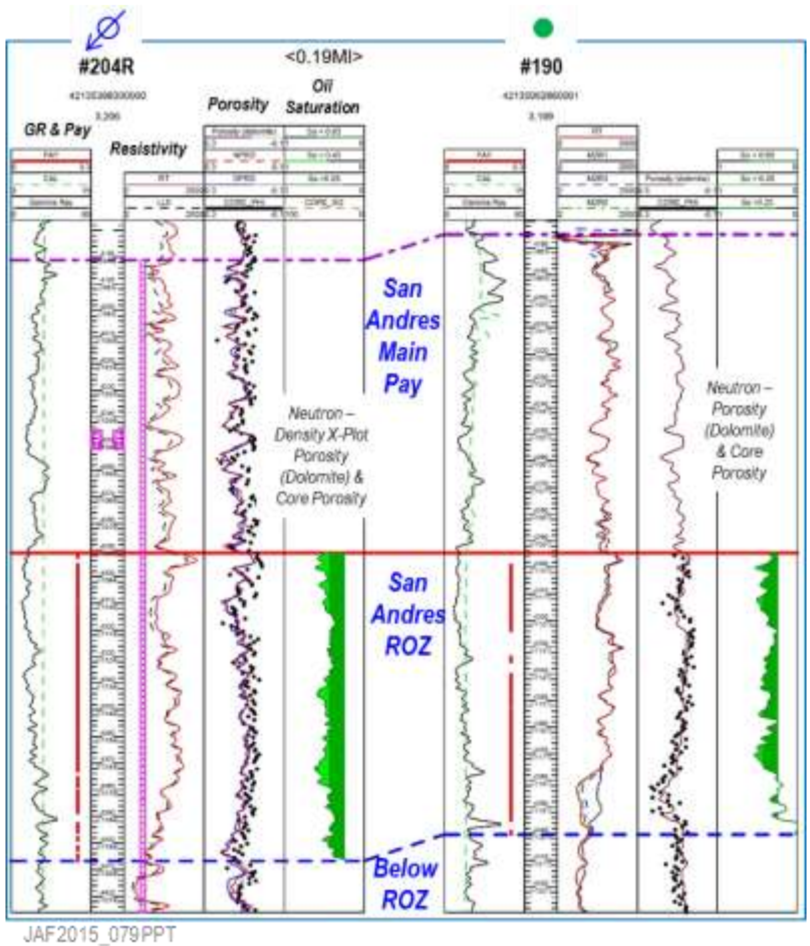
Goldsmith Field: GLSAU Geology and Volumetrics, undated, prepared by Adrian Berry, Bob Trentham, Emily Stoudt of UTPB for Legado Resources.

Key Data Used for San Andres ROZ Resource Assessment: GLSAU Wells #204R & #190

Porosity and oil saturation were computed for the San Andres ROZ for two wells in the GLSAU ROZ CO2 Injection Pilot, as shown in Figure 7.4-12. Both wells have core through the entire San Andres ROZ. Density neutron cross-plot porosity (for dolomite) was used to compute oil saturation for the 204R. Only the neutron porosity log was used for the GLSAU 190 because the density log was determined to be poor quality. Sonic logs were not available for either well.

The Archie parameters used were: 'm' = 2.3; a = '1'; 'n' = 3.4; Rw = 0.07 ohm-m. Net pay was flagged as porosity > 0.06 and So > zero.

Figure 7.4-12. Calibrating the San Andres ROZ Resource Assessment: GLSAU Wells #204R and #190



Calibrating the San Andres ROZ Resource Assessment: GLSAU Wells #204R and #190

Average log porosity for the ROZ is 11.6 % compared to average core porosity for the ROZ of 10.2%. Total net pay from log analysis is 107 ft. compared to 79 ft. from core.

Table 7.4-4 compares core analysis and log analysis for the San Andres ROZ for the GLSAU #204R. Net pay, average porosity of net pay and average oil saturation of net pay are shown for 10 foot increments in the ROZ and below the ROZ. The base of the ROZ occurs at a depth of 4,410 ft in this well. Note that the log calculated oil saturation successfully delineates the bottom of the ROZ.

Table 7.4-4. Calibrating the San Andres ROZ Resource Assessment: GLSAU Well #204R

		GLSAU 204R Core Analysis			GLSAU 204R Log Analysis		
San Andres Interval	Core Depth	Net Pay	Average Porosity of Net Pay	Average So of Net Pay	Net Pay	Average Porosity of Net Pay (Density-neutron cross plot porosity)	Average So of Net Pay
ROZ	4290-4300	4	11.1	0.21	9	11.6	0.52
	4300-4310	7	9.7	0.19	10	15.8	0.49
	4310-4320	10	14.3	0.22	10	13.2	0.40
	4320-4330	6	8.9	0.20	10	11.1	0.42
	4330-4340	6	10.0	0.20	10	10.5	0.47
	4340-4350	6	8.1	0.21	10	10.1	0.50
	4350-4360	5	8.7	0.17	10	9.0	0.46
	4360-4370	2	7.7	0.17	10	8.8	0.53
	4370-4380	5	7.4	0.21	8	11.4	0.48
	4380-4390	8	7.7	0.21	7	10.9	0.43
	4390-4400	10	10.4	0.25	6	15.4	0.43
	4400-4410	10	12.7	0.23	9	12.5	0.25
Below ROZ	4410-4420	7	10.0	0.08	8	14.8	0.07
	4420-4430	7	10.3	0.03	8	11.5	0.10
	4430-4440	10	9.8	0.02	7	13.8	0.09
	4440-4450	10	11.0	0.01	6	13.2	0.05

Average log porosity for the ROZ is 11.6 % compared to average core porosity for the ROZ of 10.2%. Total net pay from log analysis 107 ft. compared to 79 ft. from core.

Table 7.4-5 compares core analysis and log analysis for the San Andres ROZ for the GLSAU #190. Net pay, average porosity of net pay and average oil saturation of net pay are shown for 10 foot increments in the ROZ. The base of the ROZ occurs at a depth of 4,400 ft in this well.

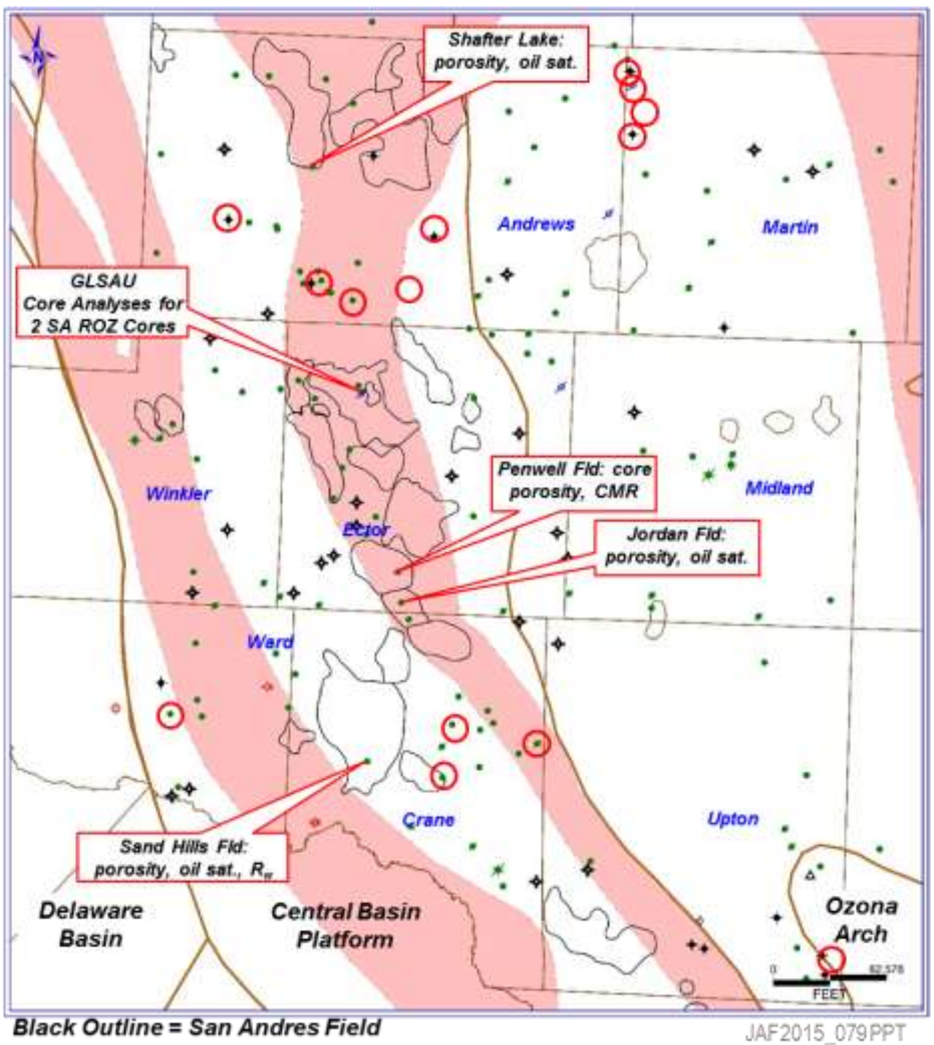
Table 7.4-5. Calibrating the San Andres ROZ Resource Assessment: GLSAU Well #190

		GLSAU 190 Core Analysis			GLSAU 190 Log Analysis		
San Andres Interval	**Core Depth**	**Net Pay**	**Average Porosity of Net Pay**	**Average So of Net Pay**	**Net Pay**	**Average Porosity of Net Pay** (neutron porosity)	**Average So of Net Pay**
ROZ	**4290-4300**	5	7.80	0.20	6.0	7.8	0.42
	4300-4310	9	10.00	0.23	10.0	8.4	0.44
	4310-4320	6	10.90	0.24	10.0	10.2	0.39
	4320-4330	2	6.7	0.16	1.0	6.3	0.30
	4330-4340	6	7.2	0.16	6.0	7.0	0.42
	4340-4350	6	8.10	0.20	9.5	7.4	0.38
	4350-4360	9	8.00	0.31	10.0	8.2	0.36
	4360-4370	8	11.20	0.33	10.0	9.2	0.47
	4370-4380	10	15.7	0.25	10.0	12.4	0.30
	4380-4390	10	17.3	0.18	10.0	15.7	0.25
	4390-4400	9	9.1	0.16	3.3	11.5	0.14
Below ROZ	**4400-4410**	10	10.6	0.08	*Log analysis does not flag any net pay below the ROZ.*		*0*
	4410-4420	10	10.3	0.04			*0*
	4420-4430	6	8.60	0.01			*0*
	4430-4440	10	9.8	0			*0*
	4440-4450	10	10.5	0			*0*

Additional Calibration of the San Andres ROZ Resource Assessment

Log calculations for the San Andres ROZ assessment were calibrated to other data, shown in Figure 7.4-13. In four producing fields, Shafter Lake, Penwell, Jordan and Sand Hills, published values for porosity and oil saturation in the 'Main Pay' were used to calibrate the calculation approach for the San Andres ROZ. At Sand Hills Field, for example, we calibrated porosity and Rw to the published values of average porosity and formation water salinity. We tested our Archie equation parameters assumed for the ROZ by matching the average "Main Pay" oil saturation for the field.

Figure 7.4-13. Calibrating the San Andres ROZ Resource Assessment



Two cores from the San Andres ROZ at GLSAU showed that the log calculations successfully delineated the ROZ interval. "ROZ-type" oil shows observed in 14 mud logs and sample logs provided support for the calculated oil saturations.

High-Grading the Permian Basin ROZ "Fairway" Resources

The ROZ "fairway" resources were further analyzed to establish volumes of higher quality and lower quality resource.

- The first step was to calculate an average log-based value for porosity and oil saturation for each study well, applying a "net pay "cut-off" value of 6% for porosity and no "net pay" cut-off value for oil saturation. (Aberrant porosity and oil saturation values were excluded from net pay, however.)

- A gamma-ray index ('shale volume') cut-off of approximately 0.4 was used to exclude apparent shale zones.

- "Higher quality" was defined as areas and well logs with average computed log values greater than 8% for porosity and greater than 25% for oil saturation (Sor).

- Similarly, "lower quality" was defined as areas and well logs with computed log values less than 8% porosity or less than 25% for oil saturation.

Establishing Higher and Lower ROZ Resource Quality

To illustrate the calculation of higher and lower quality ROZ resources, we select two logs - - one from Andrews County (representing a ROZ resource area of 40,100 acres (63 mi^2)) and one from Ward County (representing a ROZ resource area of 21,700 acres (34 mi^2)).

- Applying a 6% cut-off value for porosity and no cut-off value for oil saturation, the average porosity and Sor for the ROZ in one log (Andrews County) meets the criteria for defining higher quality ROZ resource (8 % porosity and greater than 25% for Sor). The average porosity and Sor for the other log (Ward County) do not meet the criteria.

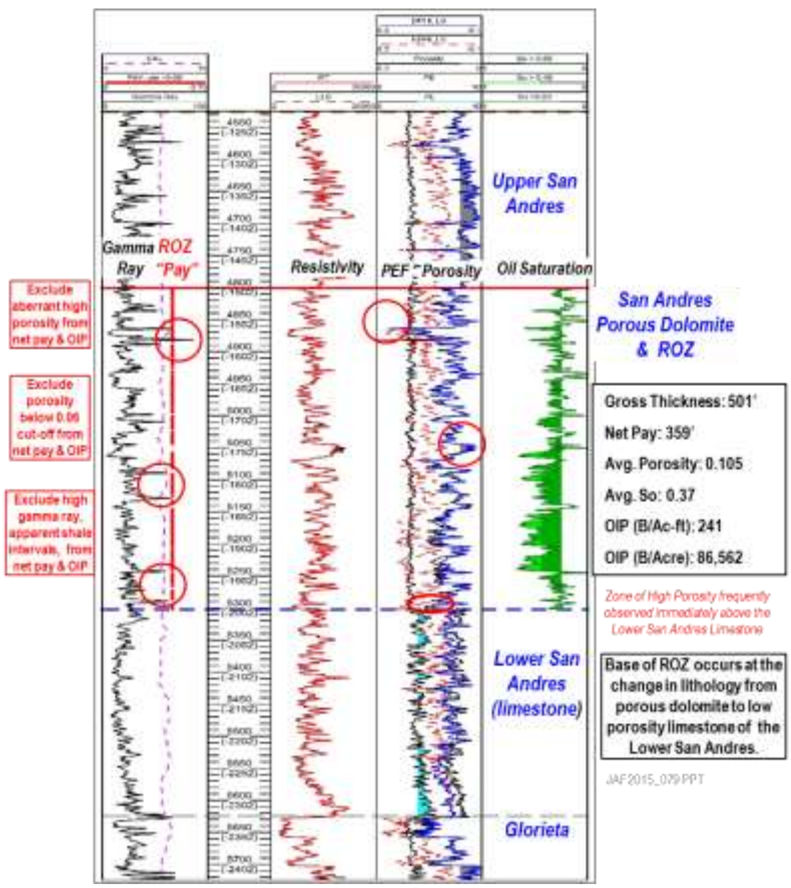
- The result is 3,471 million barrels of higher quality ROZ OIP is allocated to the area represented by the Andrews County well, and 418 million barrels of lower quality ROZ OIP is allocated to the area represented by the Ward County well.

Primary Study Methodology for High Grading the ROZ Resource ("High Quality" Resource Example – Andrews Co.)

The San Andres ROZ "net pay" interval in a pre-defined area of 40,100 acres represented by this log has an average porosity value of 10.5 percent and an average oil saturation value of 37 percent, shown in Figure 7.4-14 and Table 7.4-5.

Since both porosity and oil saturation meet the standard for higher quality, the ROZ resource in this area is categorized as higher quality, with 3,471 MMBbl of OIP.

Figure 7.4-14. Primary Study Methodology for High Grading the ROZ Resource ("High Quality" Resource Example – Andrews Co.)



Primary Study Methodology for High Grading the ROZ Resource ("Low Quality" Resource Example – Ward Co.)

The San Andres ROZ "net pay" interval in a pre-defined area of 21,700 acres represented by this log has an average porosity value of 10.8 percent and an average oil saturation value of 18 percent, shown in Figure 7.4-15 and Table 7.4-6.

Because the oil saturation value does not meet the standard for higher quality, the ROZ resource in the entire area is categorized as lower quality and is not included in the estimate of higher quality ROZ resource. The lower quality ROZ resource assessed for the entire area is 418 MMBbl of OIP.

Figure 7.4-15. Primary Study Methodology for High Grading the ROZ Resource ("Low Quality" Resource Example – Ward Co.)

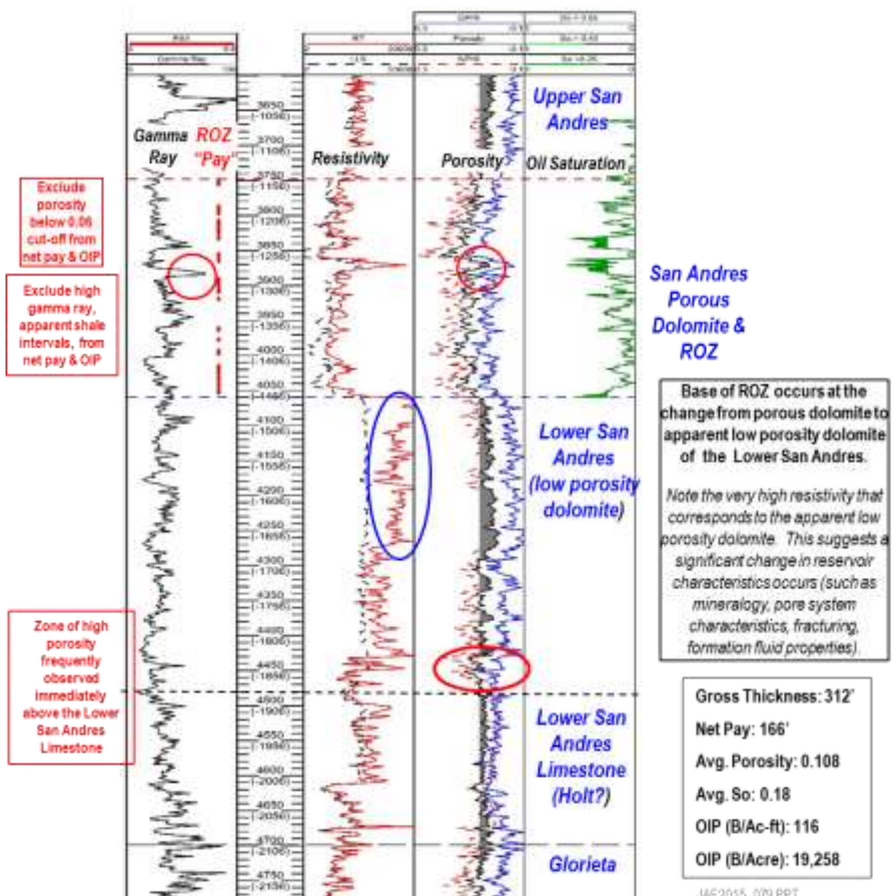


Table 7.4-6. Establishing ROZ Resource Quality

	Primary Study Methodology (Average Values for Φ and S_{or})*	
	Higher Resource Quality (Log Example #1)	**Lower Resource Quality (Log Example #2)**
Assumed Area (Acres)	40,096	21,711
ROZ 1 Gross Thickness (ft)	501	336
ROZ 1 Net Pay (ft)	359	249
Avg. Porosity (fraction)	0.105	0.108
Avg. Oil Saturation (fraction)	0.37	0.18
OIP (B/AF, net pay)	241	116
OIP (B/Acre)	86,562	19,258
OIP Resource (million barrels)	3,471	418

*Log cut-off values of 6% for porosity, no cut-off for oil saturation.
**Log cut-off values of 8% for porosity and 25% for oil saturation.

Total ROZ "Fairway" Resources: Eight Counties of the Permian Basin

The San Andres and Grayburg ROZ "fairway" oil in-place in the eight county area of the Permian Basin totals 79.47 billion barrels.

- Nearly three quarters, 58.23 billion barrels of the ROZ "fairway" resource, is higher quality, having an oil saturation greater than 25% and porosity greater than 8%.
- The remaining portion, 21.24 billion barrels of the ROZ "fairway" resource, is lower quality, with an oil saturation less than 25% and/or porosity less than 8%.

Use of additional logs and data points would, no doubt, modify the above resource assessment values.

In addition to the San Andres Fm ROZ resource assessment totaling 79.47 billion barrels, Table 7.4-7.

Table 7.4-7. ROZ "Fairway" Resources: Eight Counties of the Permian Basin

County /	Partition	Higher Quality ROZ Resources (Billion Bbls)	Lower Quality ROZ Resources (Billion Bbls)	Total ROZ Resources (Billion Bbls)
Andrews				
	#1	19.25	0.58	19.83
	#2	11.98	3.79	15.77
	#3	-	1.53	1.53
	Total	**31.23**	**5.90**	**37.13**
Martin				
	#1	4.80	1.94	6.74
	Total	**4.80**	**1.94**	**6.74**
Winkler				
	#1	6.18	-	6.18
	#2	1.80	1.49	3.29
	Total	**7.98**	**1.49**	**9.47**
Ector				
	#1	0.23	0.54	0.77
	#2	1.81	0.43	2.24
	#3	3.51	0.43	3.94
	Total	**5.55**	**1.40**	**6.95**
Three Southern Tier				
#1	(Ward Co.)	4.13	4.18	8.31
#2	(Crane Co.)	2.13	2.34	4.47
#3	(Crane Co.)	2.41	0.67	3.08
#4	(Upton Co.)	-	3.32	3.32
	Total	**8.67**	**10.51**	**19.18**
	San Andres Total	**58.23**	**21.24**	**79.47**

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7.4.3 DISCUSSION OF ROZ RESOURCE ASSESSMENT METHODOLOGY

Methodology: ROZ “Fairway” Resource Assessment

The ROZ “fairway” resource assessment for the eight county area of the Permian Basin began with an evaluation of 152 well logs that penetrate the dolomitized ROZ portions of the San Andres Fm below the main San Andres pay zone and of the Grayburg Fm below the main Grayburg pay zone. Of these, 120 well logs were selected for detailed quantitative analysis.

The San Andres ROZ occurs in the porous, pervasively dolomitized shelf deposits located between the interbedded dolomite, siltstone and evaporites of the upper San Andres and the low porosity, limestone and shale of the lower San Andres.

Each county is divided into a series of partitions. Well logs within each partition were examined to identify a higher quality and a lower quality resource “type well.” The average reservoir characteristics of lower and higher quality ROZ resources were determined for the partition. These average data were used to assess the ROZ “fairway” resource within each partition.

Methodology: ROZ “Fairway” Resource Assessment; Calculating Oil In-Place

The methodology for conducting the ROZ “fairway” resource assessment in the eight county area of the Permian Basin is as follows:

- Of the 152 digital study logs reviewed, 120 were used in the quantitative portion of the resource assessment. Porosity and oil saturation were calculated from the study logs using IHS PETRA software. The well logs included neutron, density and sonic porosity plus resistivity, gamma ray, photoelectric absorption (PEF) and caliper.
- 32 study logs were excluded from the quantitative analysis because either the wells are located inside San Andres producing oil fields; a complete log suite needed to calculate oil saturation did not extend across the entire ROZ; the logs were found to be of poor quality; or the calculated log values were averaged with another nearby well (within 0.5 miles or less.)
- A key objective of the quantitative analysis was to apply as consistent a log analysis approach as possible to the ROZ across the study area. Observed variation in the

quantity and quality of resources could then be attributed to actual change in the ROZ resource across the area rather than the log analysis approach.

- Some adjustment to the quantitative analysis is necessary across such a large study area to accommodate regional variation in formation water and reservoir characteristics. Where possible, we calibrate and adjust the quantitative approach to incorporate published reservoir data for the San Andres ROZ.

- A variable formation volume factor based on a sample San Andres oil field in each partition was used to transform reservoir oil saturation to stock-tank values.

Porosity is computed using all available logs: compensated neutron, sidewall neutron, density, and sonic logs. Neutron logs are corrected for dolomite and obvious bad values are removed.

- Gypsum is abundant in the San Andres ROZ in the Central Basin Platform, which introduces additional complexity and uncertainty to the computing log porosity. Neutron porosity reads too high in the presence of gypsum because the bound water of hydration is measured as porosity. The low grain density of gypsum (2.35 g/cc) compared to dolomite reduces the matrix density used to calculate density porosity.

- Density porosity is initially calculated from bulk density using a matrix density of 2.85 g/cc and fluid density of 1.0 – 1.05 g/cc. Density-neutron cross-plot porosity is computed using lithology-corrected logs. If gypsum is present in the reservoir, additional correction may be then be applied to further reduce the density-neutron cross-plot porosity.

- Sonic porosity is calculated using the Wylie relationship, fluid travel time = 188 m-sec/ft, and matrix travel time of 43 m-sec/ft; an approach that produced a good correlation to available San Andres ROZ core data. An additional published algorithm for sonic porosity for the San Andres at Jordan field was successfully applied in study wells in Andrews, Ector, Winkler and northern Crane counties.[8]

- The best available calculated porosity log is selected for calculating oil saturation. For most wells, this is the density-neutron cross-plot porosity or the sonic porosity.

Computing Oil Saturation in the ROZ

$$\mathbf{Sw^n = ((a \times Rw)/(Rt \times f^m))}$$

Oil saturation (So) was computed as 1- Sw

Archie Equation Parameters:

- m = 'cementation exponent'; expresses contribution of the pore network to total resistivity; influenced by grain size and pore connectivity. We use a value of 2.3* based on detailed work at the Bennett Ranch Unit of the Wasson Field[9]

- a = correction for tortuosity of electrical path in the rock pore system. We use the common default value for carbonate is of 1.

[8] * Major, R.P., and M.H. Holtz, 1997, Predicting reservoir quality at the development scale: methods for quantifying remaining hydrocarbon resource in diagenetically complex carbonated reservoirs, in J.A. Kupecz, J. Gluyas, and S. Bloch, eds., Reservoir quality prediction in sandstones and carbonates: AAPG Memoir 69, p. 231-248

[9] U.S. DOE, 1982, Field Project to Obtain Pressure Core, Wireline Log and Production Test Data for Evaluation of CO2 Flooding Potential, Texas Pacific Bennett Ranch Unit Well No. 310, Wasson (San Andres), Field, Yoakum County, TX – Final Report; DOE/MC/08341-39

- n = ‘saturation exponent’; relates water saturation to formation resistivity with the common default for carbonates being = m. For the Central Basin Platform, we use a value for ‘n’ of 3.4, derived from calibrating our calculated oil saturation to published values for the ROZ at Seminole Field.[10] For the Midland Basin, we use a value for ‘n’ of 3.0. This empirical ‘n’ value is further supported by some of the laboratory-derived values of ‘n’ from the Bennett Ranch core study that range to ‘3’ or greater.

- Rt = fluid saturated resistivity of the rock. We used the deep reading resistivity log for ‘Rt’ and used the environmentally-corrected ‘Rt’ curve provided by the logging company, if available. In most cases, very little difference was found between the Rt curve and the deep resistivity curve in the San Andres ROZ

- Rw = formation water resistivity. We use published regional produced water salinity and resistivity (Rw) values for the San Andres to compute Rw for the ROZ at formation temperature.[11] The average produced water resistivity values for all samples in the study area is 0.06 ohm-m, with produced water resistivity values for Central Basin Platform samples generally higher than Rw values computed for samples from the Midland Basin. In addition, apparent produced water resistivity values were found to increase significantly from north to south along the Central Basin Platform. For example, average Rw of 0.07 ohm-m was computed for Andrews County; but for Ward and Crane counties in the south, Rw values of 0.125 ohm-m and 0.19 ohm-m were found to be appropriate.

Log calculated oil saturation for the ROZ in the study wells is more difficult to calibrate, but several opportunities were found that guided our selection of Archie parameters and Rw to compute oil saturation. These calibration opportunities include:

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[10] M.M. Honarpur, N.R. Nagarajan, A.C. Grijalba, M. Valle and K. Adesoye, 2010, Rock-Fluid Characterization of Miscible CO2 Injection: Residual Oil Zone, Seminole Field, Permian Basin, SPE 133089

[11] Texas Water Development Board, 1972, A Survey of the Subsurface Saline Water of Texas, Vol. 2, Chemical Analyses of Saline Water, 372 pp. Also, United States Geological Survey, Produced Waters Data Base, download from http://energy.cr.usgs.gov/prov/prodwat/

For formation temperature gradient: Southern Methodist University, 2004, Geothermal Map of North America, available on-line at www.smu.edu/geothermal/GeothermalMap.

- ***Use of core from the Goldsmith-Landreth San Andres Unit.*** See discussion provided previously.

- ***Mud logs and sample logs for selected deep wildcat wells***. A few high quality mud logs were found which offered evidence of ROZ-type oil shows in the San Andres that helped to corroborate the log calculated oil saturations.

- ***Well logs from deep units within the boundaries of producing San Andres field***. Such wells may have a full log suite through the San Andres Main Pay and ROZ, although the well never tested the San Andres. Calculating oil saturation for both the Main Pay and the ROZ often helped to calibrate the ROZ calculation, especially when the calculated oil saturation for the "Main Pay" seemed appropriate for a producing San Andres field.

- ***Published field studies and petrophysical studies of the San Andres Formation***. Although historically these studies are focused on the Main Pay, many provide summary data of San Andres reservoir characteristics and valuable insights into well log analysis for the San Andres which can be applied to the ROZ.

Published Field and Petrophysical Studies of the San Andres Formation

Numerous published field studies of the San Andres Formation were reviewed. Several published studies were particularly useful for stratigraphic correlations, for calculating porosity in individual study wells, and for understanding porosity variations throughout the study area. Some of the key studies consulted for the ROZ assessment are listed here.

- Dull, D.W., 1995, Reservoir characterization and the application of geostatistics to three-dimensional modeling of a shallow ramp carbonate, Mabee San Andres Field, Andrews and Martin Counties, Texas in Hydrocarbon Reservoir Characterization (SC34), Society of Sedimentary Geology.

- Garber, R.A. and P. M. Harris, 1986, Depositional facies of Grayburg/San Andres dolomite reservoirs, Central Basin Platform, Permian Basin, in D.G Bebout and P.M. Harris, eds., Geologic and Engineering Approaches in Evaluation of San Andres/ Grayburg Hydrocarbon Reservoirs, Permian Basin SEPM Publication 86-26, p. 61-66.

- Harris, P.M., 2008, Unique Approaches to Analysis of a Cyclic Shelf Dolomite Reservoir, AAPG Search and Discovery Article 40304 (2008).
- Holtz, M.H., 2002, Characterization of Permian Shallow-Water Dolostone, Society of Petroleum Engineers, SPE 75214, 16 pp.
- Major, R.P., and M.H. Holtz, 1997, Predicting reservoir quality at the development scale: methods for quantifying remaining hydrocarbon resource in diagenetically complex carbonated reservoirs, in J.A. Kupecz, J. Gluyas, and S. Bloch, eds., Reservoir quality prediction in sandstones and carbonates: AAPG Memoir 69, p. 231-248.
- Major, R.P., Bebout, D.G., and F.J. Lucia, 1988, Deposition facies and porosity distribution, Permian (Guadalupian) San Andres and Grayburg Formations, P.J.W.D.M field complex, Central Basin Platform, west Texas in Giant Oil and Gas Fields, republished 2012, Society of Sedimentary Geology.
- Todd, R.G., 1976, Oolite bar progradation, San Andres Formation, Midland Basin, Texas, American Association of Petroleum Geologists Bulletin, v. 60, no. 6, p.907-925.

7.4.4E San Andres Residual Oil Zone Resource: Andrews County

Andrews County, Texas contains 37.13 billion barrels of oil in-place in the residual oil zone (ROZ) outside the limits and structural closure of the existing oil fields in the county. Andrews County has been divided into three distinct partitions, with oil in-place and resource quality values provided for each partition, as shown in Table 7.4-8.

Table 7.4-8. Residual Oil Zone Resource: Andrews County

Partitions	**ROZ Resource** (Billion Barrels)		
	Higher Quality	**Lower Quality**	**Total**
#1	19.25	0.58	19.83
#2	11.98	3.79	15.77
#3	-	1.53	1.53
Total	**31.23**	**5.90**	**37.13**

A significant portion of the ROZ oil in-place resource in the Central Basin Platform (western) portion of Andrews County, 31.23 billion barrels, has higher quality reservoir properties (porosity greater than 8% and oil saturation equal to or greater than 25%). The remainder of the ROZ oil in-place resource, 5.90 billion barrels, has lower quality reservoir properties (porosity equal to or less than 8% and oil saturation of less than 25%).

Partitions 1 and 2 of Andrews County contain both higher and lower quality ROZ oil in-place resources. Partition 3, located in the Midland Basin portion of eastern Andrews County, has only lower quality ROZ oil in-place resources.

Geographic and Geologic Setting

Andrews County, Texas covers a 960,500 acre (1,500 mi2) area. Approximately two-thirds of the county encompasses the Central Basin Platform. The remainder of the area is east of this prominent Permian Basin feature, but within the extent of the southward prograding Lower and Middle San Andres shelf margins.

The county contains numerous large San Andres oil fields - - Emma, Fuhrman-Mascho, Fullerton, Mabee, Means, Midland Farms, Shafter Lake, among others. The ROZ resource below these and other existing San Andres oil fields has been excluded from the resource assessment of the ROZ “fairway” in Andrews County.

The currently mapped outline of the ROZ “fairway” encompasses the central portion of Andrews County, with the eastern and western-portions of the county deemed to be outside of the “fairway” boundaries.

A total of 35 logs that penetrate the San Andres ROZ were evaluated to provide the primary information for this Andrews County study. Of these, 23 wells were selected for the quantitative resource assessment. Additional raster logs and mug logs were reviewed to guide the acquisition and interpretation of the digital log data.

Andrews County Partitions and Study Wells

Figure 7.4E-1, the Andrews County map shows: (1) the location of 35 study wells; (2) the three ROZ “fairway” partitions; (3) the boundaries of the currently defined ROZ “fairway”; (4) the outline of the Central Basin Platform; and (5) the area excluded from the San Andres ROZ “fairways” resource assessment. The map also shows location of the major San Andres oil fields excluded from the ROZ “fairway” assessment.

Figure 7.4E-2 shows four stratigraphic “cross-sections correlate the San Andres ROZ interval within Andrews County.

Figure 7.4E-3 shows Andrews County Cross-Section A-A, Figure 7.4E-4 shows Andrews County Cross-Section B-B’, Figure 7.4E-5 shows Andrews County Cross-Section C-C’, and Figure 7.4E-6 shows Andrews County Cross-Section D-D’.

Figure 7.4E-7 shows logs for Andrews County San Andres ROZ “Type Well” 42-003-37529.

Figure 7.4E-1. Andrews County Partitions and Study Wells

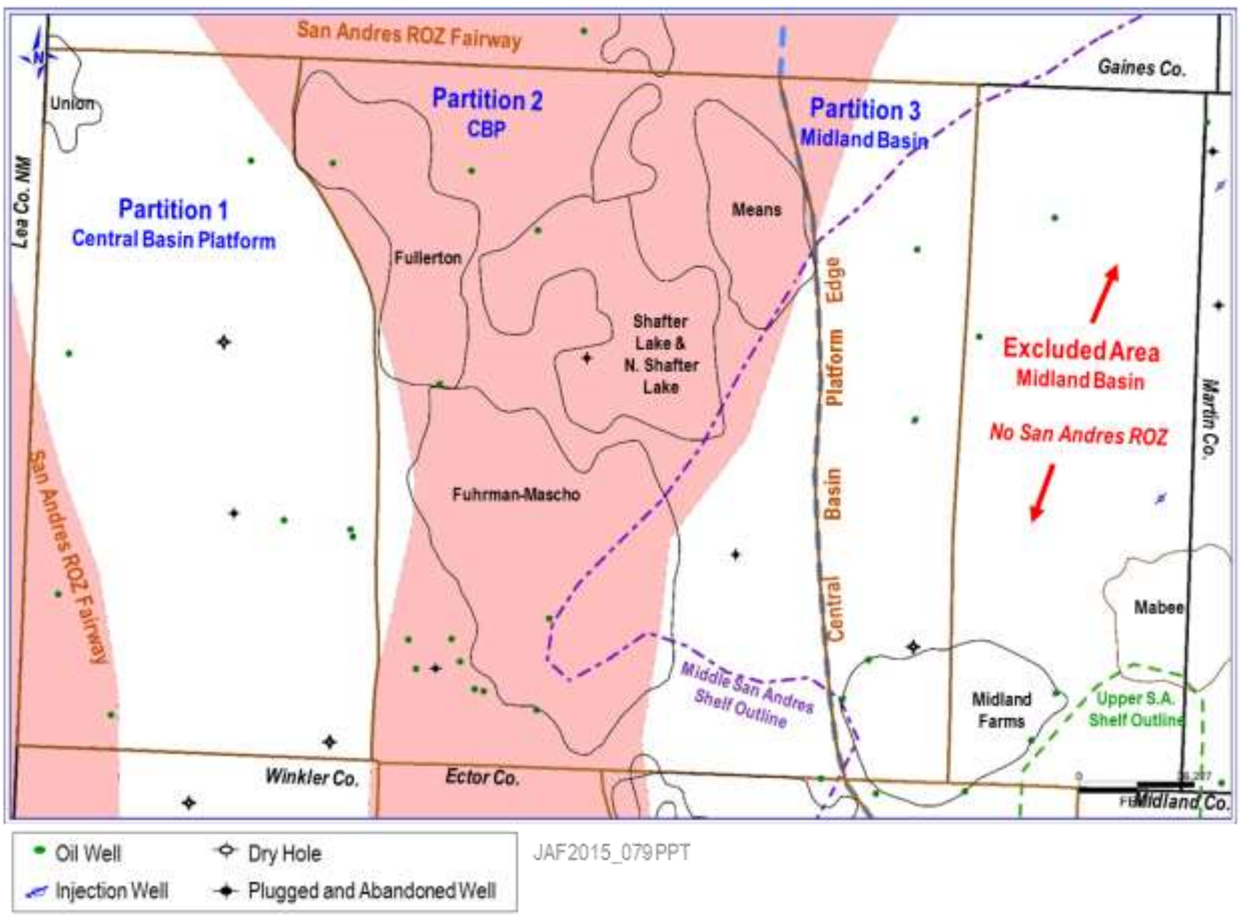


Figure 7.4E-2. Andrews County Cross-Sections

Four stratigraphic "cross-sections correlate the San Andres ROZ interval within Andrews County.

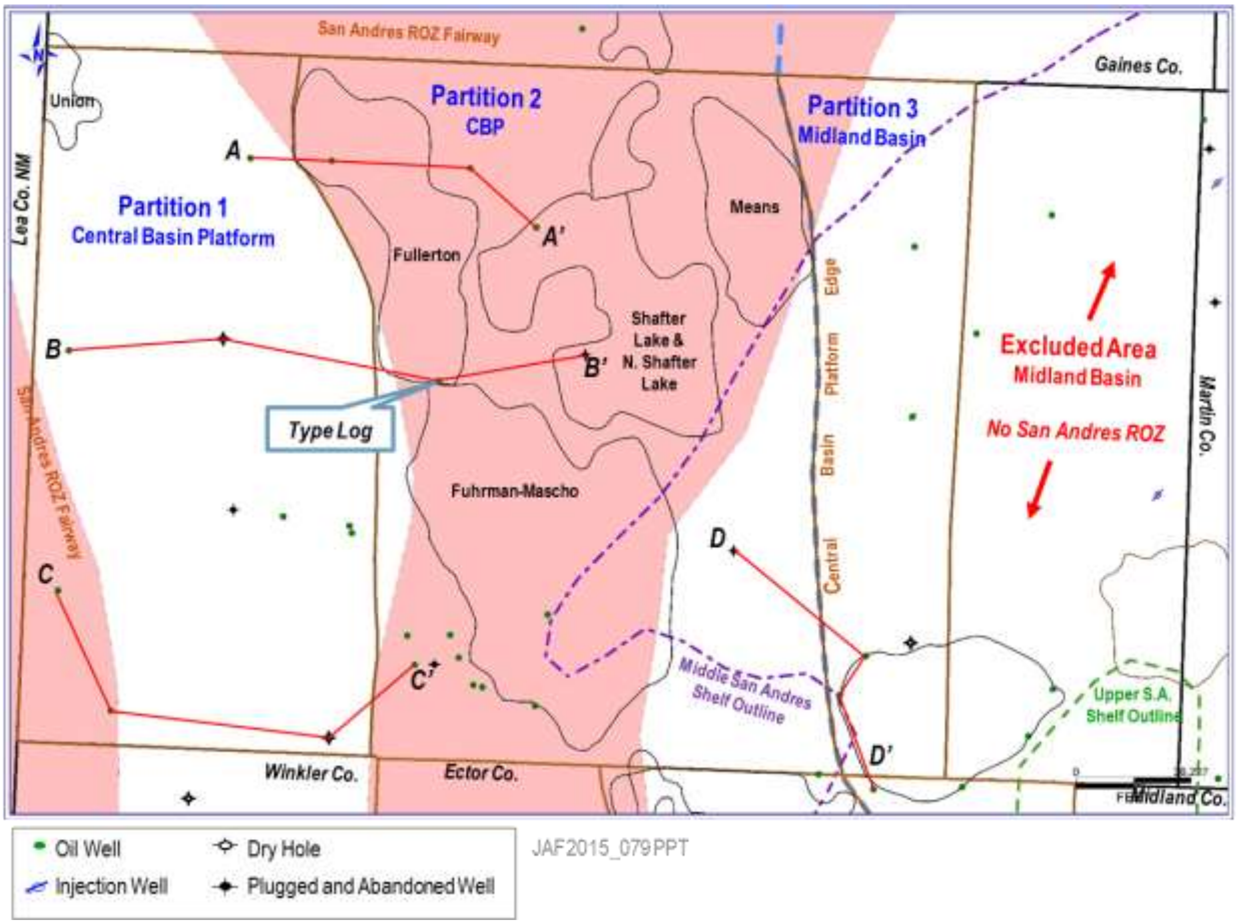
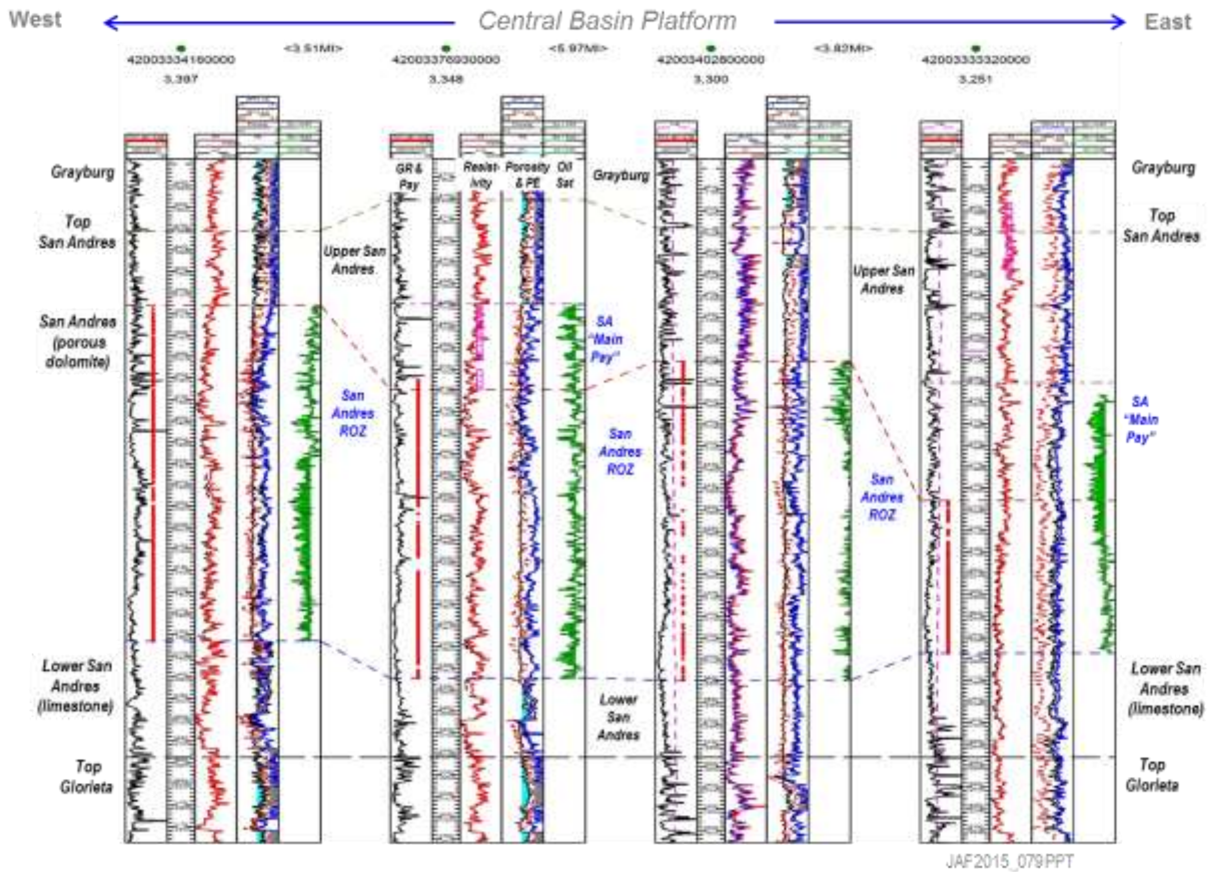


Figure 7.4E-3. Andrews County Cross-Section A-A



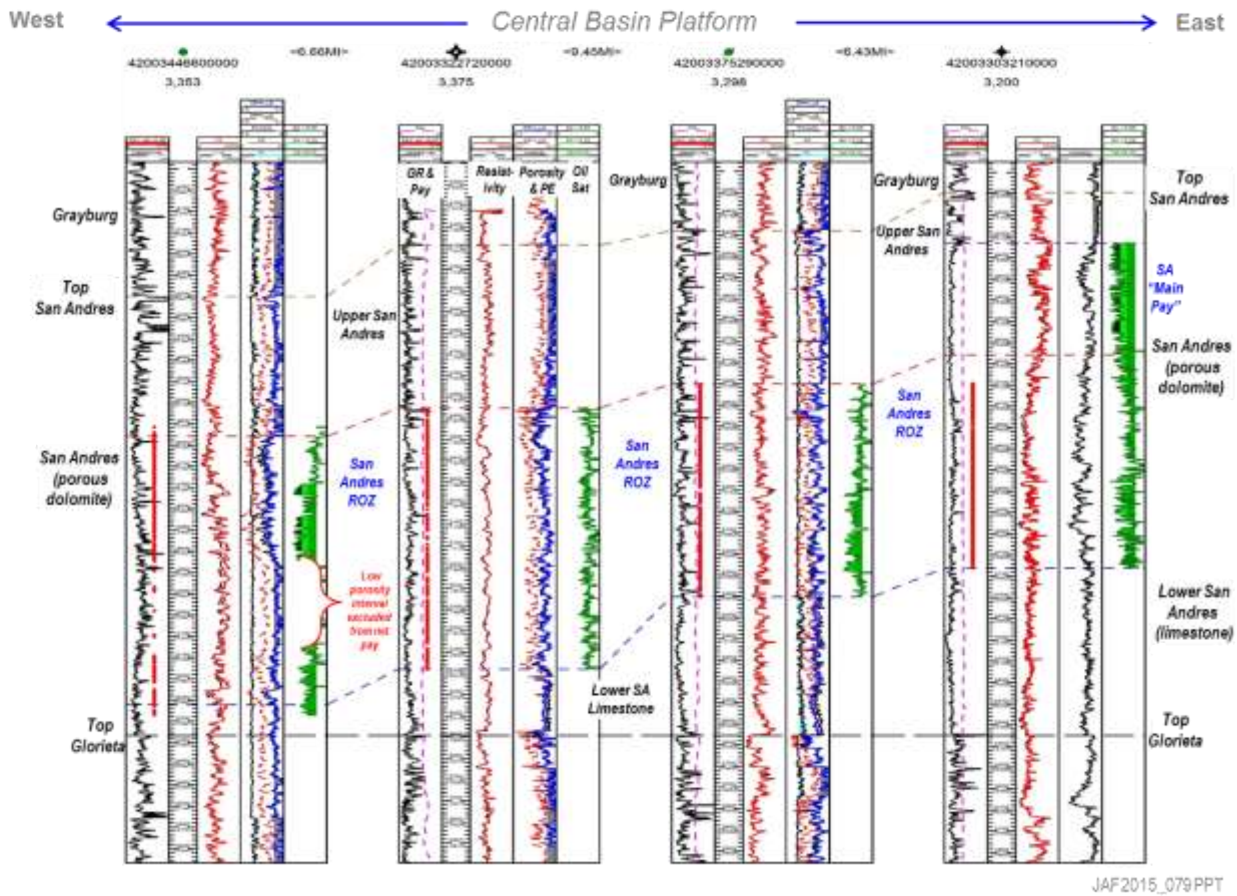
Stratigraphic cross-section on top of Glorieta. Major depth increment =50 ft.; Minor depth increment = 10 ft. ; San Andres "Main Pay" is excluded from ROZ "fairways" resource assessment.

Log Analysis Parameters: Rw = 0.07; a = 1; m = 2.3; n = 3.4.

All porosity logs are density-neutron cross-plot porosity or lithology-corrected neutron porosity. Gray shading indicates porosity less than 0.06. Green shading in Track 4 indicates calculated So between 0.25 and 0.45.

Vertical red bar in Track 1 = net pay indicator where ROZ "pay" has porosity >0.06; no Sor pay cutoff applied.

Figure 7.4E-4. Andrews County Cross-Section B-B'



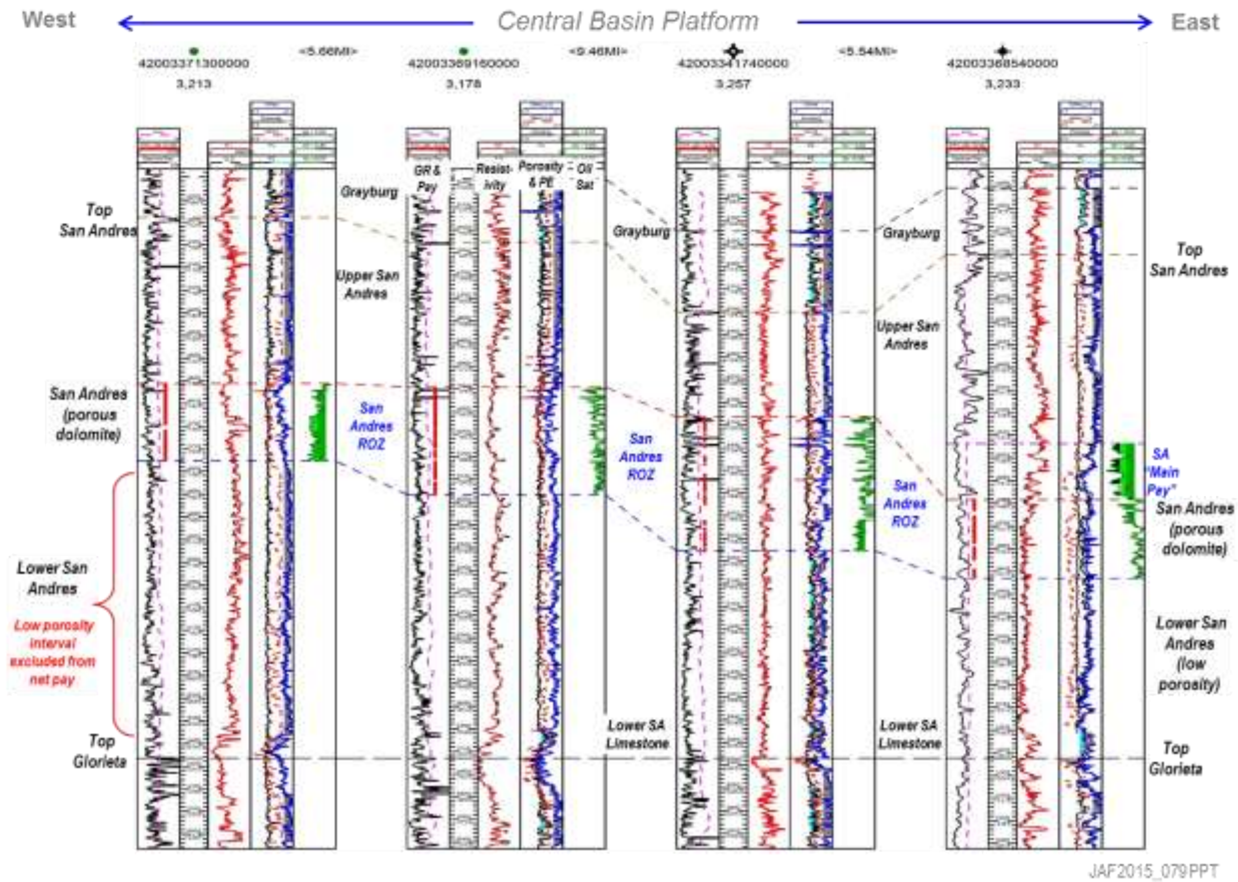
Stratigraphic cross-section on top of Glorieta. Major depth increment =50 ft.; Minor depth increment = 10 ft. ; San Andres apparent "Main Pay" interval is excluded from ROZ "fairways" resource assessment.

Log Analysis Parameters: $R_w = 0.07$; $a = 1$; $m = 2.3$; $n = 3.4$.

All porosity logs are density-neutron cross-plot porosity or lithology-corrected neutron porosity. Gray shading indicates porosity less than 0.06. Green shading in Track 4 indicates calculated S_o between 0.25 and 0.45.

Vertical red bar in Track 1 = net pay indicator where ROZ "pay" has porosity >0.06; no Sor pay cutoff applied.

Figure 7.4E-5. Andrews County Cross-Section C-C'



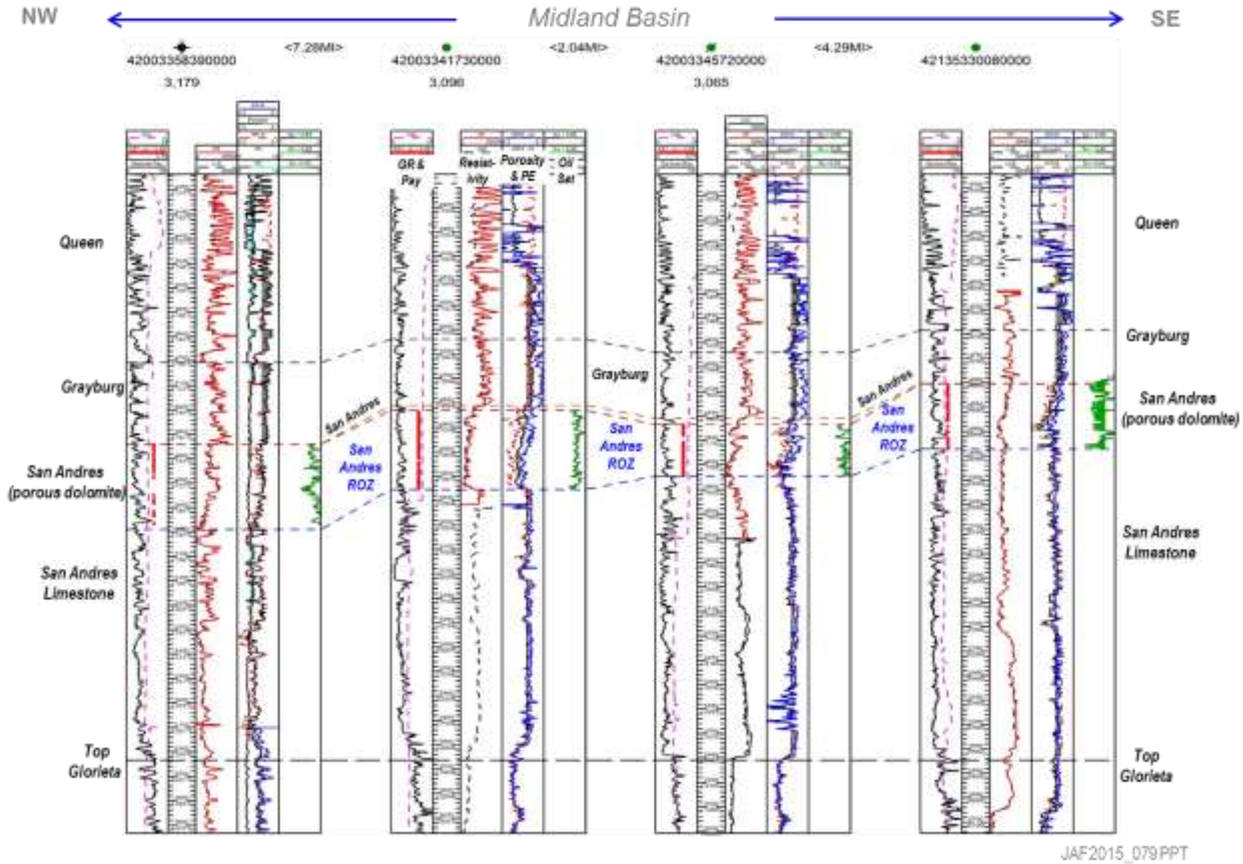
Stratigraphic cross-section on top of Glorieta. Major depth increment =50 ft.; Minor depth increment = 10 ft. ; San Andres apparent "Main Pay" interval is excluded from ROZ "fairways" resource assessment.

Log Analysis Parameters: Rw = 0.07; a = 1; m = 2.3; n = 3.4.

All porosity logs are density-neutron cross-plot porosity or lithology-corrected neutron porosity. Gray shading indicates porosity less than 0.06. Green shading in Track 4 indicates calculated So between 0.25 and 0.45.

Vertical red bar in Track 1 = net pay indicator where ROZ "pay" has porosity >0.06; no Sor pay cutoff applied.

Figure 7.4E-6. Andrews County Cross-Section D-D’



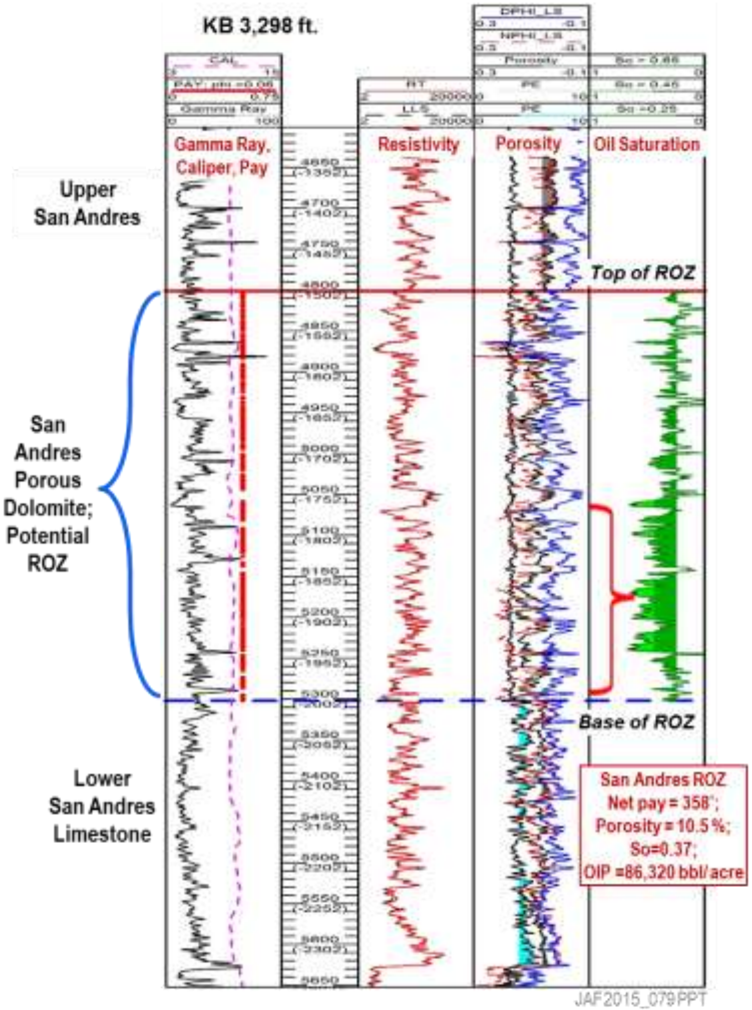
Stratigraphic cross-section on top of Glorieta. Major depth increment =50 ft.; Minor depth increment = 10 ft. ; San Andres apparent “Main Pay” interval is excluded from ROZ “fairways” resource assessment.

Log Analysis Parameters: Rw = 0.07; a = 1; m = 2.3; n = 3.4.

All porosity logs are density-neutron cross-plot porosity or lithology-corrected neutron porosity. Gray shading indicates porosity less than 0.06. Green shading in Track 4 indicates calculated So between 0.25 and 0.45.

Vertical red bar in Track 1 = net pay indicator where ROZ “pay” has porosity >0.06; no Sor pay cutoff applied.

Figure 7.4E-6. Andrews County San Andres ROZ "Type Well" 42-003-37529



- Density and neutron porosity logs are corrected for dolomite & a cross-plot porosity is used to compute oil saturation.
- Cross-plot porosity is shown in black. Uncorrected neutron porosity (limestone) shown in red. Uncorrected density porosity (limestone) shown in blue.
- Calculated porosity less than the net pay cut-off value of 0.06 is shaded gray.
- Type well is a Clear Fork test located in the San Andres "Fairway", at the boundary of a large San Andres Field.
- Potential ROZ is approx. 500' thick. Base of ROZ is low porosity limestone of the Lower San Andres.
- Note that the best resource potential appears to be deep in the ROZ, above the Lower San Andres limestone.
- Archie parameters used to compute oil saturation: Rw=0.07 ohm-m, m=2.3, n=3.4, a=1. Average oil saturation = 37%; Avg. porosity = 10.5%

Partitioning the ROZ "Fairway" Resource

The ROZ "fairway" in Andrews County is partitioned into three distinct areas. Individual ROZ "fairway" resource assessments were undertaken for each of the three partitioned areas. A portion of eastern Andrews County encompassing 192,500 acres has been excluded because the San Andres ROZ is absent.

Partition #1. Covers a 268,800 acre (420 mi^2) area of western Andrews County on the Central Basin Platform. The Union oil field, covering 2,700 acres (4 mi^2), has been excluded from the resource assessment area of Partition #1, leaving a "fairway" area of 266,100 acres (416 mi^2).

Partition #2. Covers a 380,000 acre (594 mi^2) area of central Andrews County on the Central Basin Platform. Five large San Andres oil fields - - Emma (5,400 acres), Fuhrman-Mascho (49,600 acres), Fullerton (13,600 acres), Means (14,900 acres), and Shafter Lake (15,800 acres) have been excluded from the resource assessment area for Partition #2, leaving an area of 280,700 acres (279 mi^2).

Partition #3. Covers an 119,200 acre (186 mi^2) area of northeastern Andrews County in the Midland Basin. An 8,400 acre (13 mi^2) area, encompassing the western portion of Midland Farms San Andres oilfield has been excluded from the resource assessment area for Partition #3, leaving a "fairway" area of 110,800 acres (173 mi^2).

Partition #1: Western Andrews County

Partition #1, located in western Andrews County, covers a "fairway" area of 266,100 acres (416 mi^2) on the southern portion of the Permian Basin.

- The partition is located west of the currently defined ROZ "fairway" boundary.
- The resource assessment for Partition #1 used 9 distinct log analysis-based reservoir properties data points from 10 distinct wells. (The reservoir properties from two closely-spaced well logs were averaged.)
- The partition excludes the Union oil field and its 2,700 acres.

The ROZ "type wells" and average reservoir properties for the ten San Andres ROZ wells in Partition #1 of Andrews County are shown in Table 7.4-9.

Table 7.4-9. Average Reservoir Properties Partition #1: Western Andrews County

	Average Reservoir Properties			
	ROZ "Type Wells"		ROZ	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Depth (to Top) (ft)	4,830	4,950	4,640	4,950
Gross Thickness (ft)	614	246	526	246
Net Pay (ft)	405	153	327	153
Avg. Porosity (fraction)	0.103	0.095	0.110	0.095
Avg. Oil Saturation (fraction)	0.27	0.21	0.35	0.21
Formation Volume Factor	1.20	1.20	1.20	1.20
OIP (B/AF, for net pay)	180	129	249	129
OIP (B/Acre)	72,800	19,700	80,400	19,700

The ROZ interval in Partition #1 of Andrews County contains 19.83 billion barrels of oil in-place (OIP). The bulk of the ROZ resource in Partition #1 is higher quality (porosity greater than 8% and oil saturation greater than 25%). Eight of the nine log-based ROZ data points meet the higher resource quality criteria.

- Higher quality ROZ resource - - 19.25 billion barrels
- Lower quality ROZ resource - - 0.58 billion barrels

Partition #2: Central Andrews County

Partition #2, located in central Andrews County, covers a "fairway" area of 280,700 acres (594 mi^2) of the Central Basin Platform to the south.

- The partition is located primarily inside the currently defined San Andres ROZ "fairway".
- The resource assessment for Partition #2 used 8 distinct log analysis-based reservoir properties data points from 9 district wells. (The reservoir properties from two closely-spaced well logs were averaged.)
- The partition excludes 99,300 acres under the Emma, Fuhrman-Mascho, Fullerton, Means and Shafter Lake oil fields.

The ROZ "type wells" and average reservoir properties for the nine San Andres ROZ wells in Partition #2 of Andrews County are as shown In Table 7.4-10.

Table 7.4-10. Average Reservoir Properties Partition #2: Central Andrews County

	Average Reservoir Properties			
	ROZ "Type Wells"		ROZ	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Depth (to Top) (ft)	4,800	4,690	4,690	4,940
Gross Thickness (ft)	501	213	516	412
Net Pay (ft)	358	195	377	216
Avg. Porosity (fraction)	0.105	0.112	0.114	0.106
Avg. Oil Saturation (fraction)	0.37	0.24	0.32	0.19
Formation Volume Factors	1.25	1.25	1.25	1.25
OIP (B/AF, for net pay)	241	163	226	125
OIP (B/Acre)	86,300	31,700	85,200	27,000

The ROZ interval in Partition #2 of Andrews County contains 15.77 billion barrels of oil in-place (OIP). The bulk of ROZ resource in Partition #2 is higher quality. Four of the eight log-based ROZ data points meet the higher quality criteria (porosity greater than 8% and oil saturation greater than 25%).

- Higher quality ROZ resource - - 11.98 billion barrels
- Lower quality ROZ resource - - 3.79 billion barrels

Partition #3: Eastern Andrews County – Midland Basin

Partition #3, located in northeastern Andrews County, covers a “fairway” area of 110,800 acres (186 mi^2) in the Midland Basin (east of the Central Basin Platform) of the Permian Basin.

- The partition is to the east of the currently defined San Andres ROZ “fairway” boundary.
- The resource assessment for Partition #3 used 4 distinct log analysis-based reservoir properties data points.
- The partition excludes 8,400 acres below the western part of Midland Farms oil field.

The ROZ “type wells” and average reservoir properties for the four San Andres ROZ wells in Partition #3 of Andrews County are shown in Table 7.4-11.

Table 7.4-11. Average Reservoir Properties Partition #3: Eastern Andrews County

	Average Reservoir Properties	
	ROZ "Type Wells"	ROZ
	Lower Quality	Lower Quality
Depth (to Top) (ft)	4,770	4,950
Gross Thickness (ft)	105	133
Net Pay (ft)	73	77
Avg. Porosity (fraction)	0.127	0.121
Avg. Oil Saturation (fraction)	0.15	0.21
Formation Volume Factor	1.10	1.10
OIP (B/AF, for net pay)	134	179
OIP (B/Acre)	9,800	13,800

:

The ROZ interval in Partition #3 of Andrews County contains 1.53 billion barrels of oil in-place (OIP). All of the ROZ area and ROZ resource in Partition #3 is lower quality. All of the four log-based ROZ data points fall below the higher resource quality criteria (porosity greater than 8% and oil saturation greater than 25%).

- Higher quality ROZ resource - - none
- Lower quality ROZ resource - - 1.53 billion barrels

7.4.4F San Andres Residual Oil Zone Resource: Martin County

Martin County, Texas contains 6.74 billion barrels of oil in-place in the San Andres residual oil zone (ROZ) outside the limits and structural closure of the existing oil fields in the county.

We have placed Martin County into one San Andres ROZ partition, with oil in-place and resource quality values provided in Table 7.4-12.

Table 7.4-12. San Andres Residual Oil Zone Resource: Martin County

Partitions	**ROZ Resource** (Billion Barrels)		
	Higher Quality	**Lower Quality**	**Total**
#1	4.80	1.94	6.74
Total	**4.80**	**1.94**	**6.74**

The bulk of the San Andres ROZ oil in-place resource in Martin County, 4.80 billion barrels, has higher quality reservoir properties (porosity greater than 8% and oil saturation equal to or greater than 25%).

The remainder of the San Andres ROZ oil in-place resource in Martin County, 1.94 billion barrels, has lower quality reservoir properties (porosity equal to or less than 8% and oil saturation of less than 25%).

Geographic and Geologic Setting

Martin County, Texas covers a 586,100 acre (916 mi^2) area, with 353,700 acres (553 mi^2) of the county area containing the San Andres ROZ resource. The western portion of Martin County covering 232,400 acres (363 mi^2) where the San Andres ROZ is absent (and replaced by the Grayburg ROZ), has been excluded from the San Andres ROZ resource assessment.

The currently mapped outlines of the ROZ “fairway” encompasses the eastern portion of Martin County. A total of 7 logs that penetrate the San Andres ROZ were evaluated to provide the primary information for this Martin County study, with all 7 of the wells selected for the quantitative portion of the resource assessment. Additional raster logs and mug logs were reviewed to guide the acquisition and interpretation of the digital log data.

Figure 7.4F-1, the Martin County map shows: (1) the location of 7 San Andres study wells in Partition #1 and the 10 Grayburg study wells in the western portion of the county; (2) the one San Andres ROZ "fairway" partition; (3) the boundaries of the currently defined ROZ "fairway". All of Martin County is within the Midland Basin. The map shows the approximate positions of the eastern shelf edge during late San Andres and middle San Andres deposition.[12]

Figure 7.4F-2 shows two stratigraphic cross-sections showing the correlation of the San Andres and Grayburg ROZ intervals in Martin County.

Figure 7.4F-3 shows Martin County Cross-Section A-A and Figure 4-2-4 shows Martin County Cross-Section B-B'.

Figure 7.4F-4 shows logs for Martin County San Andres ROZ "Type Well" 42-317-31531.

[12] Ward, R.F., Kendall, C., Harris, P.M., 1986, Upper Permian (Guadalupian) Facies and Their Association with Hydrocarbons – Permian Basin, West Texas and New Mexico, AAPG Bulletin, V. 70, No.3, p. 239-262

Figure 7.4F-1. Martin County Partitions and Study Wells

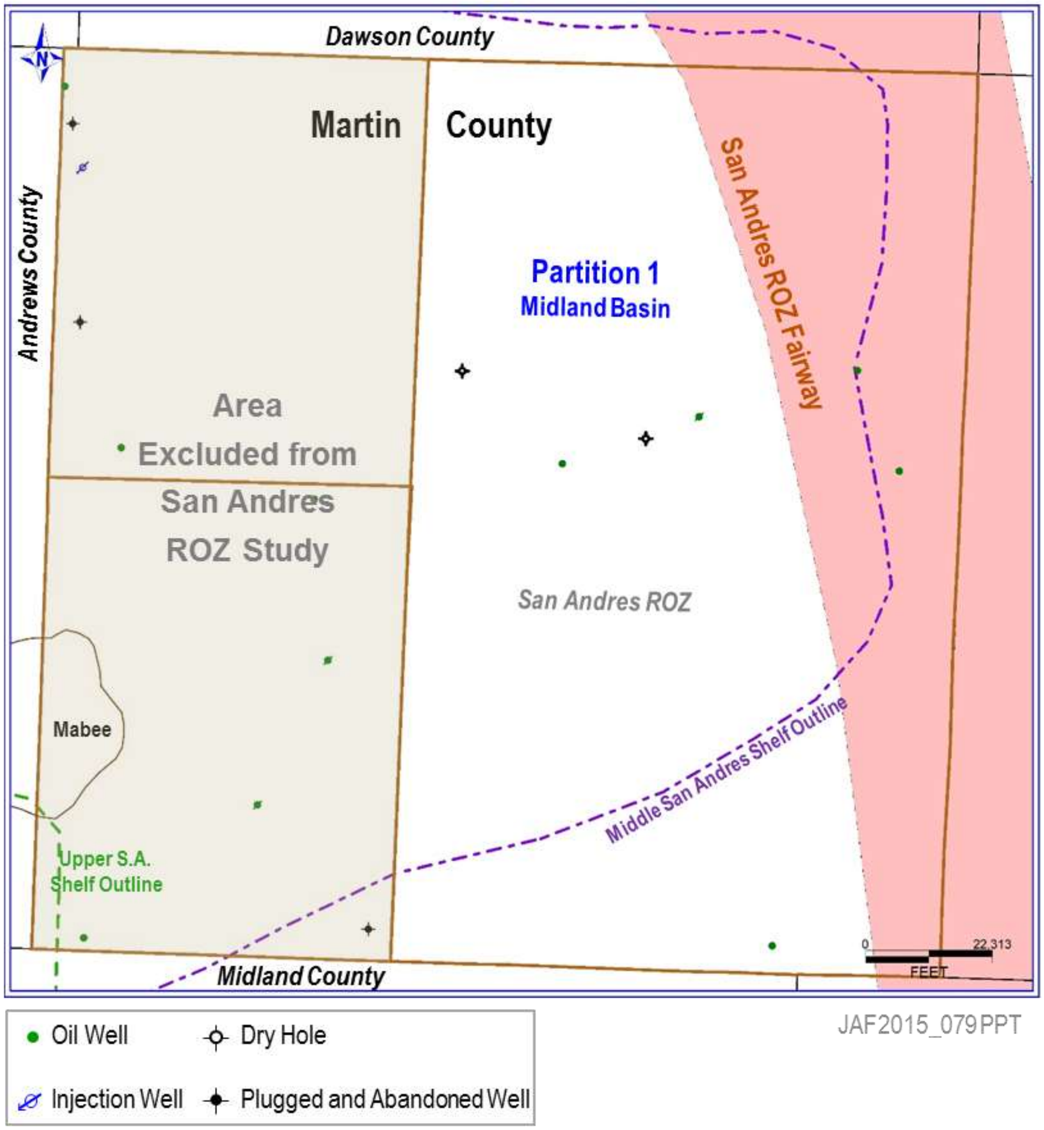


Figure 7.4F-2. Martin County Cross-Sections

Two stratigraphic cross-sections show the correlation of the San Andres and Grayburg ROZ intervals in Martin County.

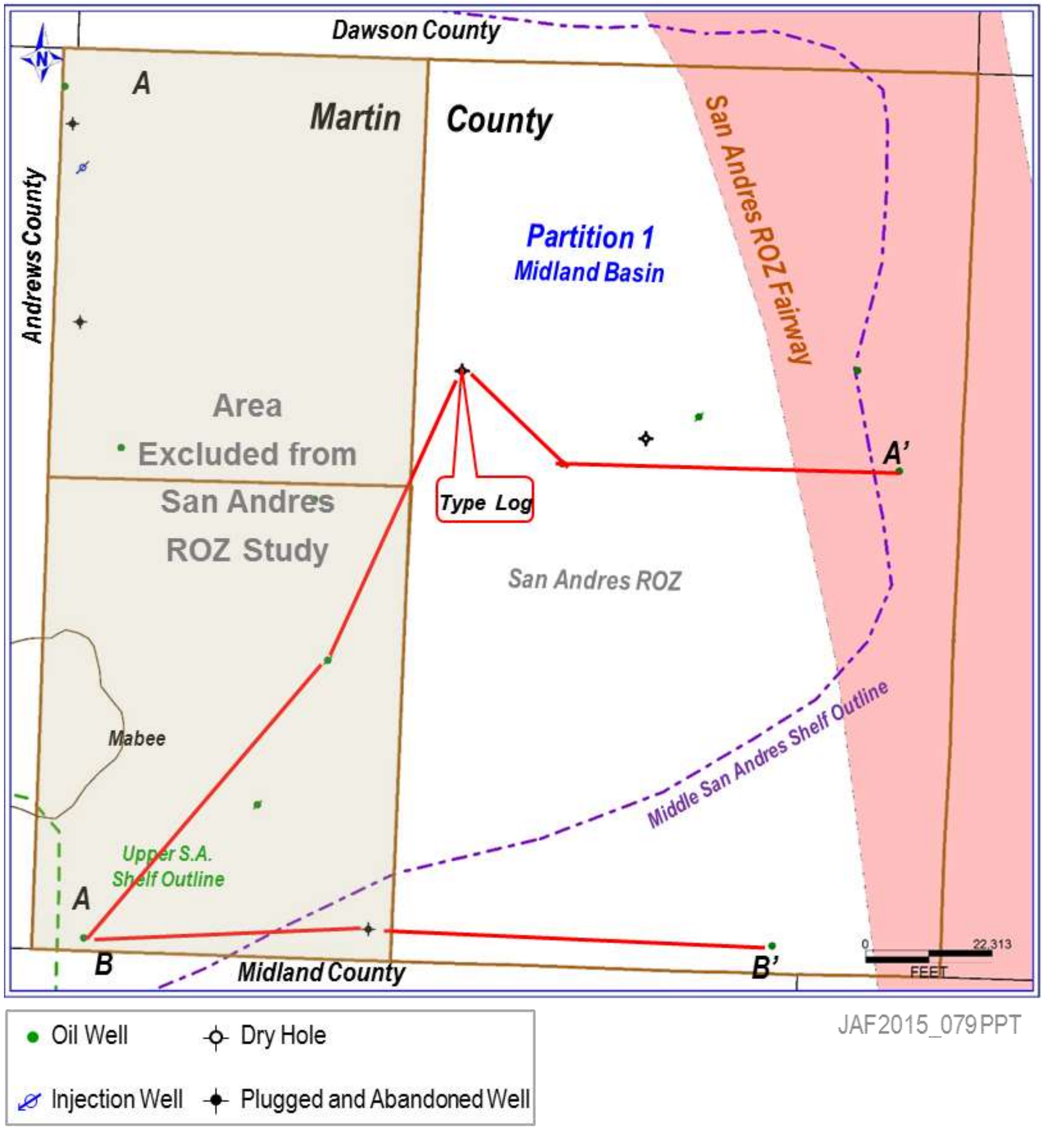
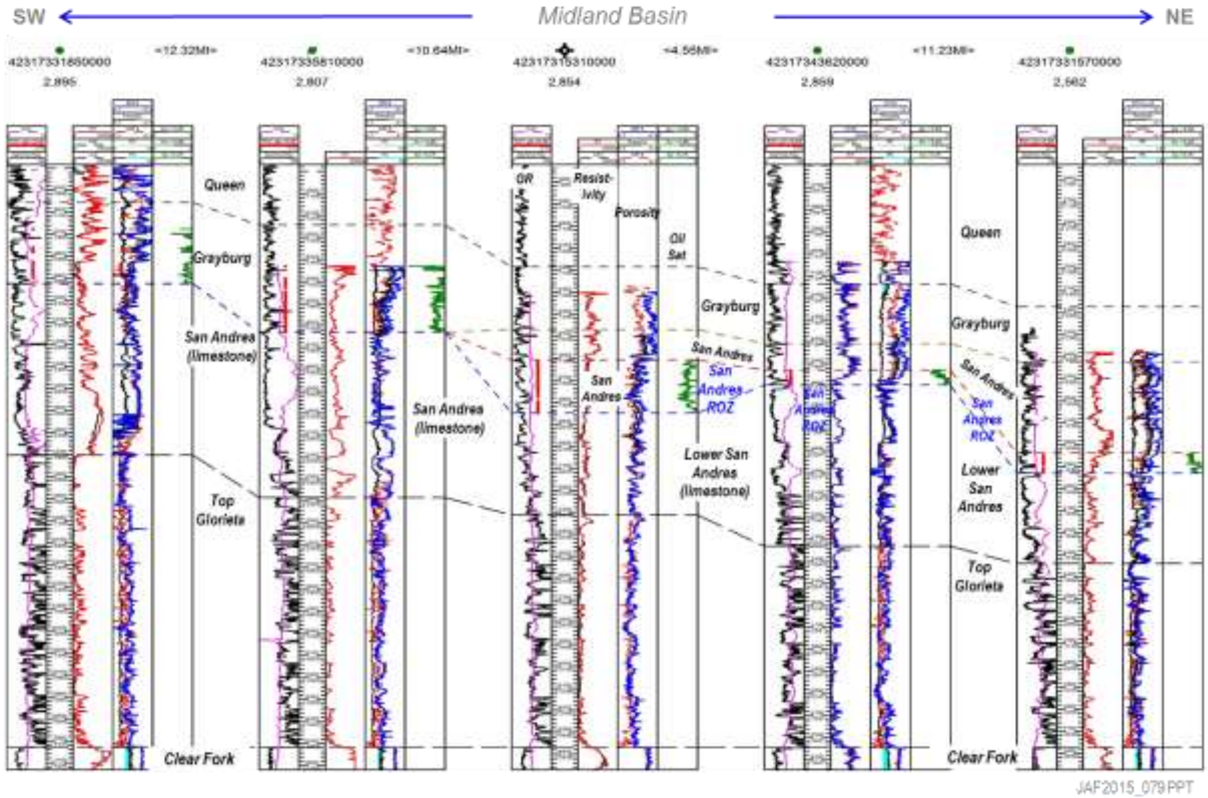


Figure 7.4F-3. Martin County Cross-Section A-A'



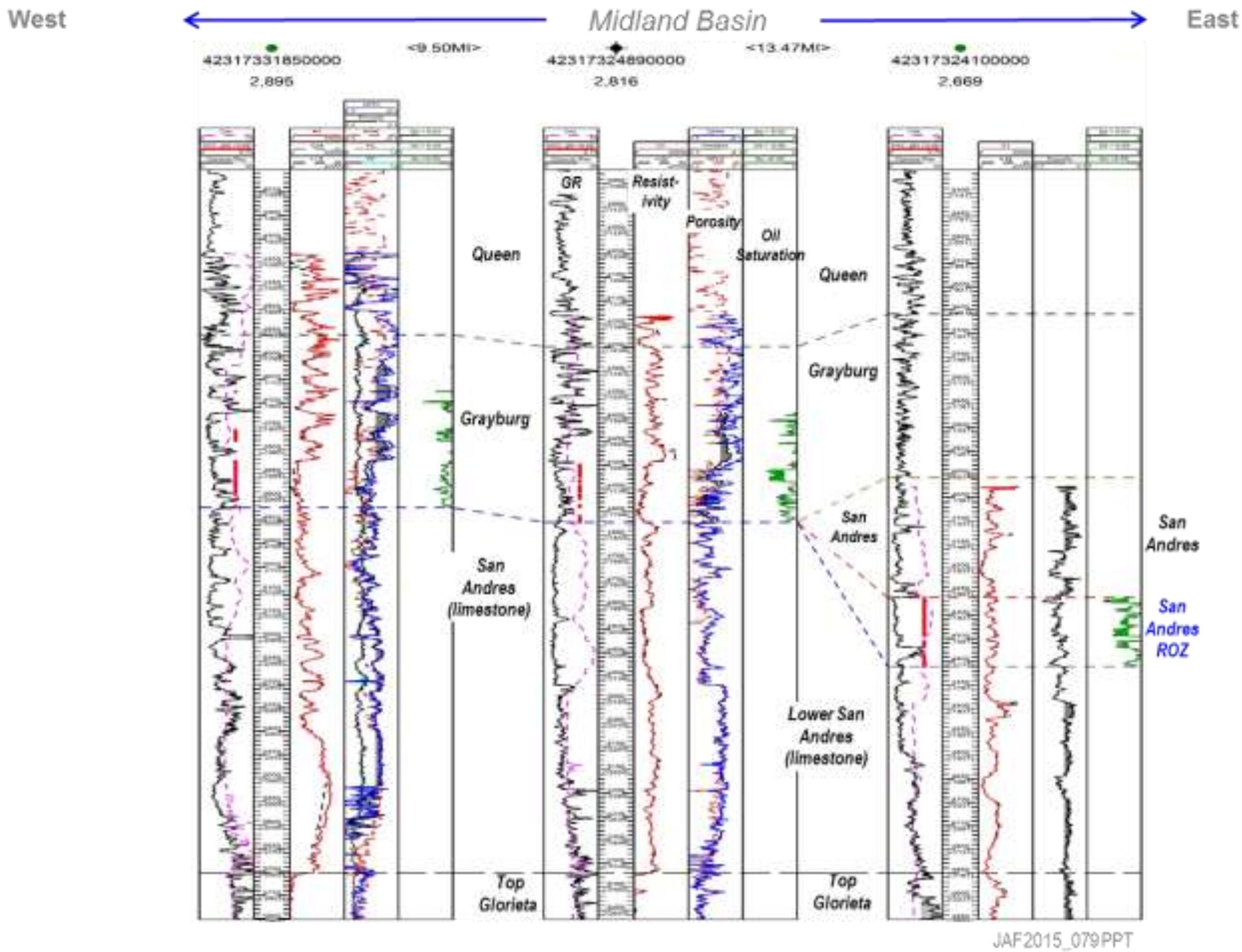
Stratigraphic cross-section on top of Clear Fork. Major depth increment =100 ft.; Minor depth increment = 20 ft.

Log Analysis Parameters: Rw = 0.05; a = 1; m = 2.3; n = 3.0.

All porosity logs are density-neutron cross-plot porosity or lithology-corrected neutron porosity. Gray shading indicates porosity less than 0.06. Green shading in Track 4 indicates calculated So between 0.25 and 0.45.

Vertical red bar in Track 1 = net pay indicator where ROZ "pay" has porosity >0.06 ; no Sor pay cutoff applied

Figure 7.4F-4. Martin County Cross-Section B-B'



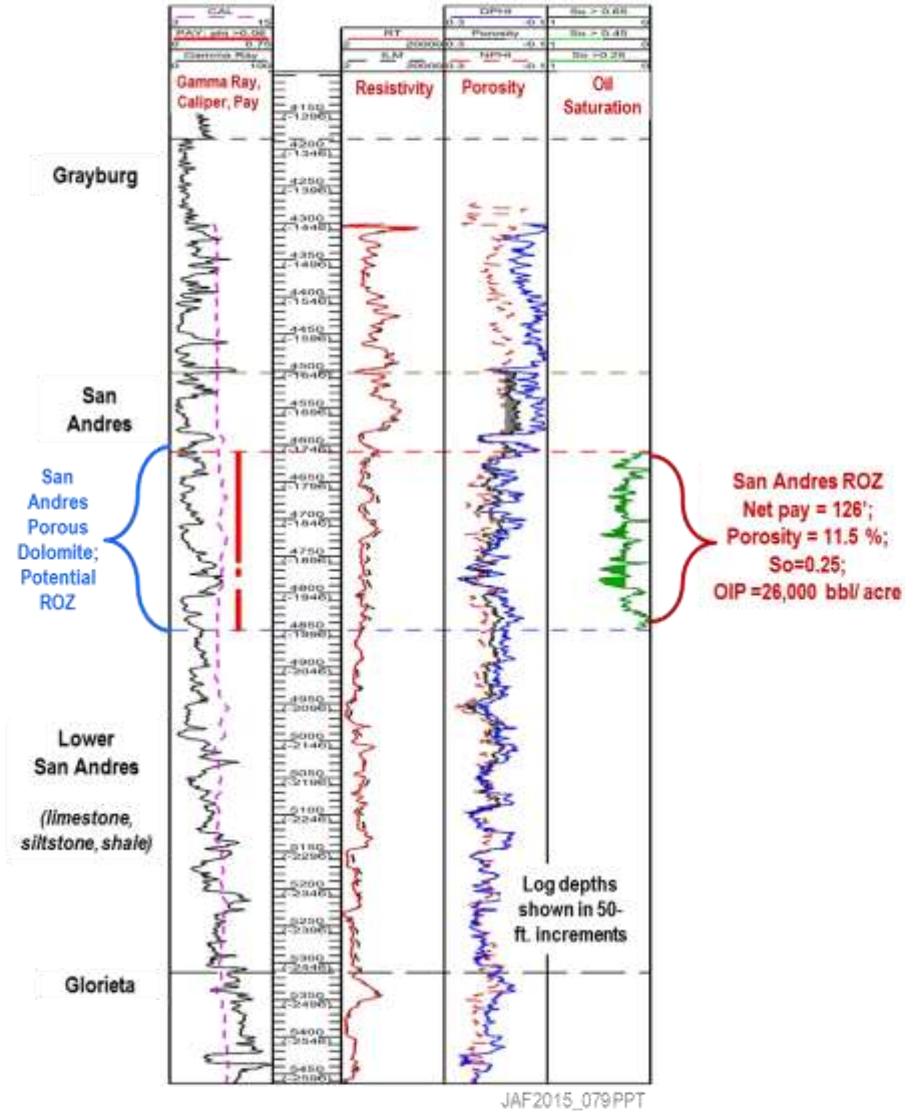
Stratigraphic cross-section on top of Glorieta. Major depth increment =50 ft.; Minor depth increment = 10 ft.

Log Analysis Parameters: Rw = 0.05; a = 1; m = 2.3; n = 3.0.

All porosity logs are density-neutron cross-plot porosity or lithology-corrected neutron porosity. Gray shading indicates porosity less than 0.06. Green shading in Track 4 indicates calculated So between 0.25 and 0.45.

Vertical red bar in Track 1 = net pay indicator where ROZ "pay" has porosity >0.06; no Sor pay cutoff applied.

Figure 7.4F-5 Martin County San Andres ROZ “Type Well” 42-317-31531



- Density and neutron porosity logs are corrected for dolomite, and a cross-plot of porosity and resistivity is used to compute oil saturation.
- Final cross-plot porosity is shown in black. Uncorrected neutron porosity (limestone) shown in red. Uncorrected density porosity (limestone) shown in blue.
- Calculated porosity < 0.06 is shaded in dark gray.
- Calculated oil saturation > 0.25 is shaded green.
- Archie equation parameters for calculating oil saturation from well logs: Rw=.05, ‘m’ = 2.3, ‘n’ = 3.0; ‘a’ = 1.00

Partition #1: Eastern Martin County

Partition #1, located in eastern Martin County, covers an area of 353,700 acres (533 mi^2) in the Permian Basin.

- The eastern portion of the partition contains a portion of the currently defined San Andres ROZ "fairway".
- The resource assessment for Partition #1 used 7 distinct log analysis-based reservoir properties data points.
- The partition does not contain any major San Andres Fm oil fields.

The ROZ "type wells" and average reservoir properties for the seven San Andres ROZ wells in Partition #1 of Martin County are shown in Table 7.4-13.

Table 7.4.13. Average Reservoir Properties Eastern Martin County

	Average Reservoir Properties			
	ROZ "Type Wells"		ROZ – San Andres	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Depth to Top (ft)	3,900	4,230	4,154	4,350
Gross Thickness (ft)	161	228	120	140
Net Pay (ft)	133	171	102	98
Avg. Porosity (fraction)	0.095	0.116	0.108	0.121
Avg. Oil Saturation (fraction)	0.36	0.14	0.30	0.15
Formation Volume Factors	1.08	1.08	1.08	1.08
OIP (B/AF, for net pay)	246	117	233	130
OIP (B/Acre)	32,700	20,000	23,800	12,800

The San Andres ROZ interval in Partition #1 of Martin County contains 6.74 billion barrels of oil in-place (OIP). The bulk of the ROZ resource in Partition #1 is higher quality. Four of the seven log-based ROZ data points meet the higher quality criteria (porosity greater than 8% and oil saturation greater than 25%).

- Higher quality ROZ resource - - 4.80 billion barrels
- Lower quality ROZ resource - - 1.94 billion barrels

7.4.4G San Andres Residual Oil Zone Resource: Winkler County

Winkler County, Texas contains 9.47 billion barrels of oil in-place in the residual oil zone (ROZ) outside the limits and structural closure of the existing oil fields in the county.

Winkler County has been divided into two distinct partitions, with oil in-place and resource quality values provided for each partition, as shown in Table 7.4-14.

Table 7.4.-14. Residual Oil Zone Resources: Winkler County

Partitions	ROZ (Billion Barrels)		
	Higher Quality	**Lower Quality**	**Total**
#1	6.18	-	6.18
#2	1.80	1.49	3.29
Total	**7.98**	**1.49**	**9.47**

A significant portion of the ROZ oil in-place resource, 7.98 billion barrels, in the Central Basin Platform (central and eastern) portion of Winkler County, has higher quality reservoir properties (porosity greater than 8% and oil saturation equal to or greater than 25%).

The remainder of the ROZ oil in-place resource, 1.49 billion barrels, has lower quality reservoir properties (porosity equal to or less than 8% and oil saturation of less than 25%).

Partition #1 of Winkler County only contains higher quality ROZ oil in-place resources, while Partition #2 of Winkler County contains both higher and lower quality ROZ oil in-place resources.

Geographic and Geologic Setting

Winkler County, Texas covers a 342,800 acre (536 mi^2) area. Approximately two-thirds of the county is located on the Central Basin Platform. The remainder of the area is west of this prominent Permian Basin feature and is located in the Delaware Basin where the San Andres formation is absent.

The county does not contain any large San Andres oil fields. The currently mapped outlines of the ROZ "fairway" encompasses the central portion of Winkler County. The eastern portion of Winkler County is outside of the "fairway" boundary. The western portion of Winkler County, in the Delaware Basin, is excluded because the San Andres formation is absent.

A total of 12 logs that penetrate the San Andres ROZ were evaluated to provide the primary information for the Winkler County ROZ resource assessment. Additional raster logs and mug logs were reviewed to guide the acquisition and interpretation of the digital log data.

Figure 7.4G-1 shows the Winkler County map showing: (1) the location of the 12 study wells; (2) the two ROZ "fairway" partitions; (3) the boundaries of the currently defined ROZ "fairway"; and (4) the outline of the Central Basin Platform.

Figure 7.4G-2 shows two stratigraphic "working-level" cross-sections created to correlate the ROZ interval within Winkler County. Figure 4-3-3 shows Winkler County Cross-Section A-A' and Figure 7.4G-4 Winkler County Cross-Section B-B'.

Figure 7.4G-5 shows logs for Winkler County San Andres ROZ "Type Well" 42-495-30371; KB 3216.

Figure 7.4G-1. Winkler County Partitions and Study Wells

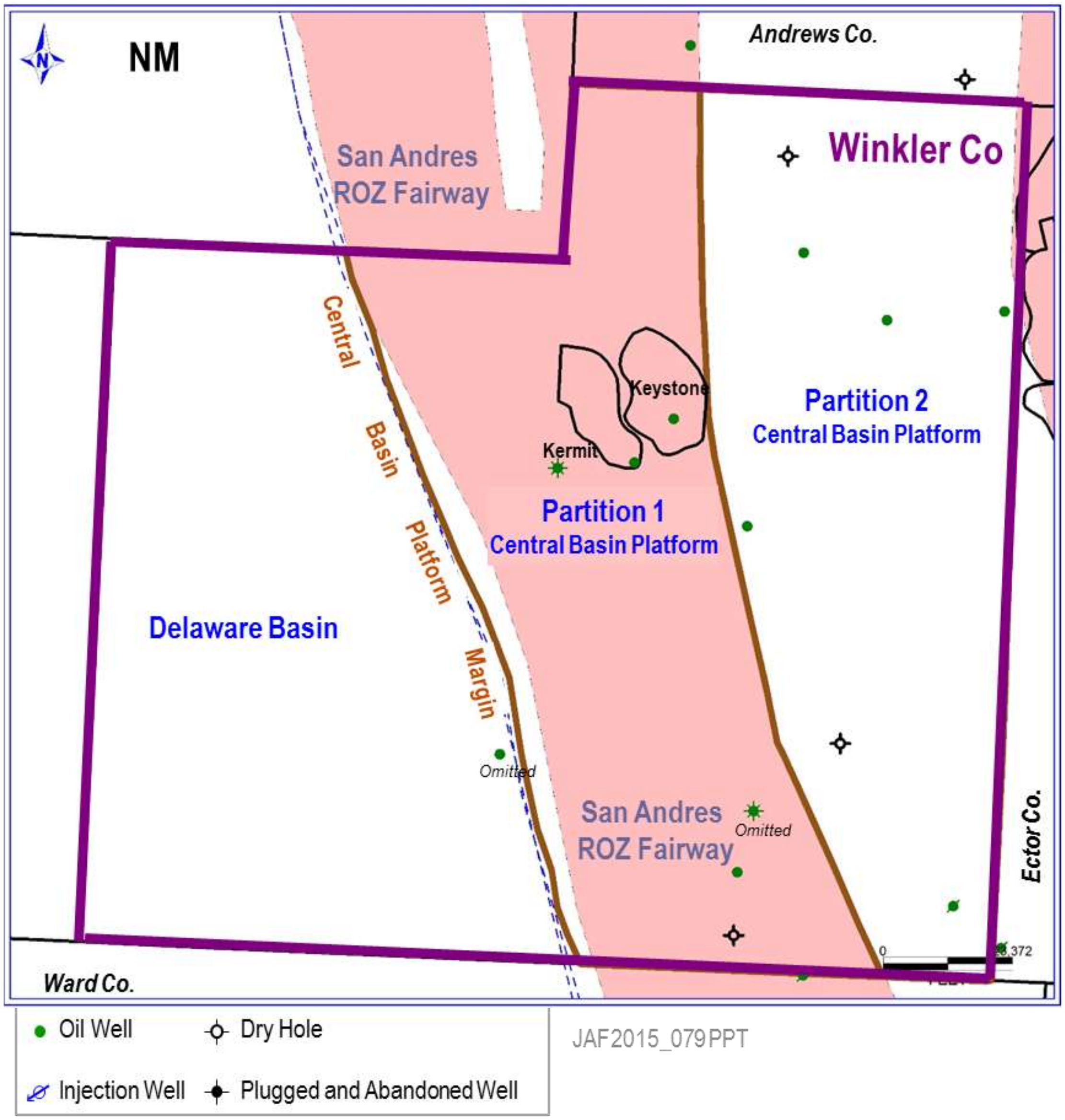
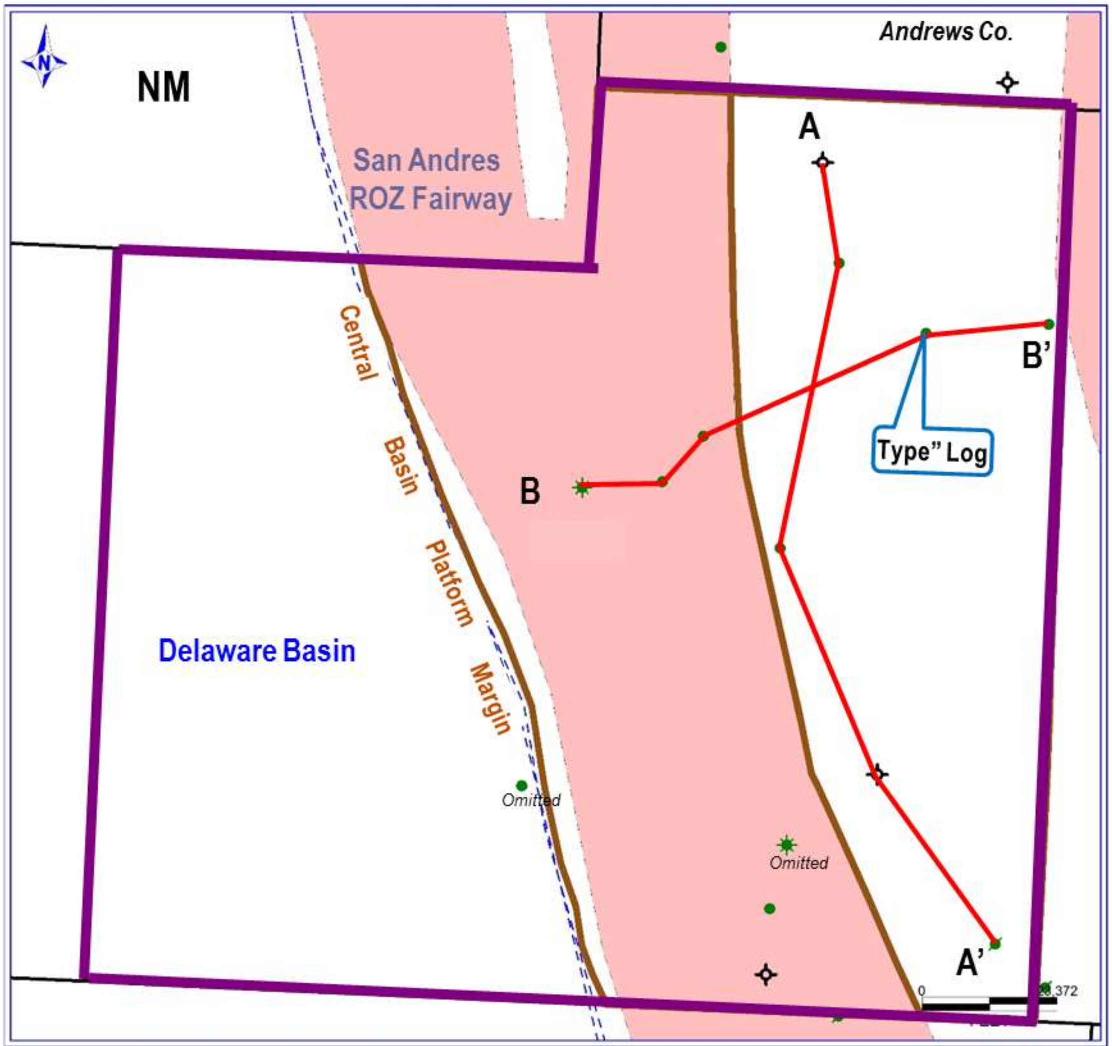


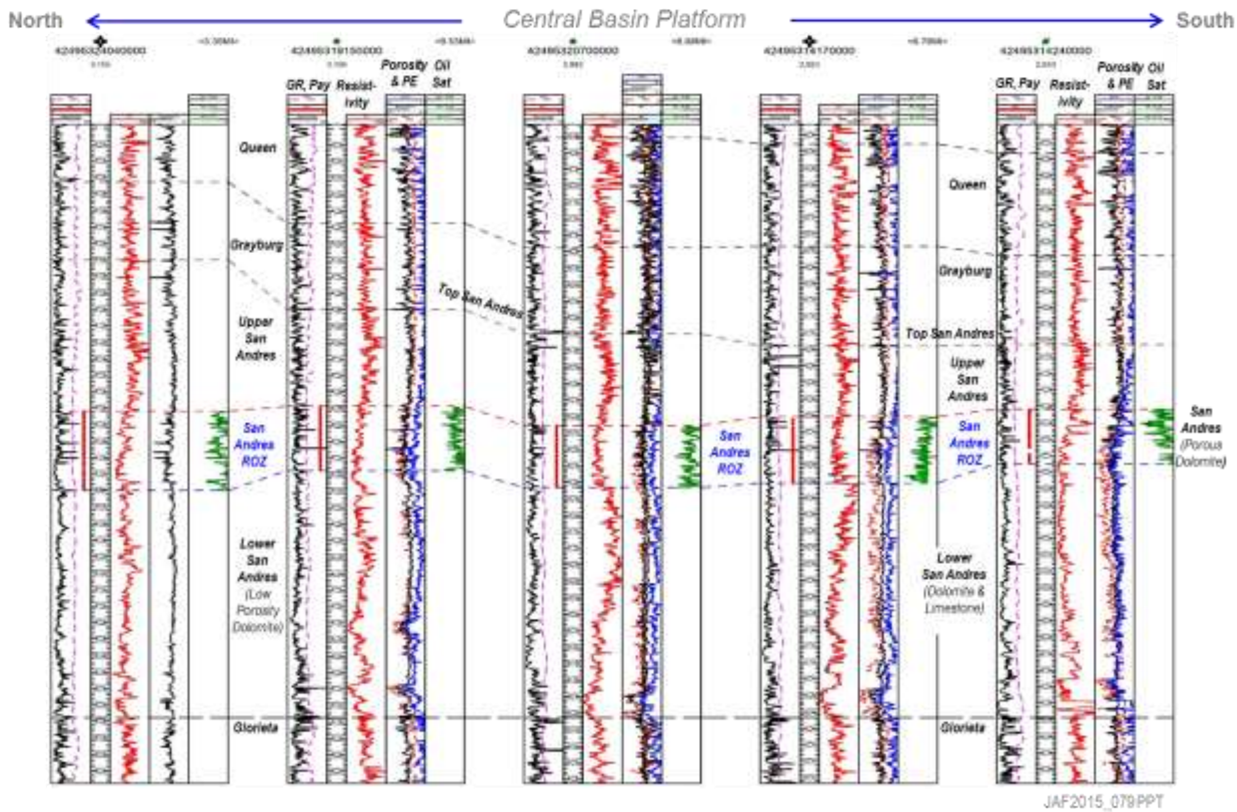
Figure 7.4G-2. Winkler County Cross-Sections

Two stratigraphic "working-level" cross-sections were created to correlate the ROZ interval within Winkler County.



JAF2015_079PPT

Figure 7.4G-3. Winkler County Cross-Section A-A'

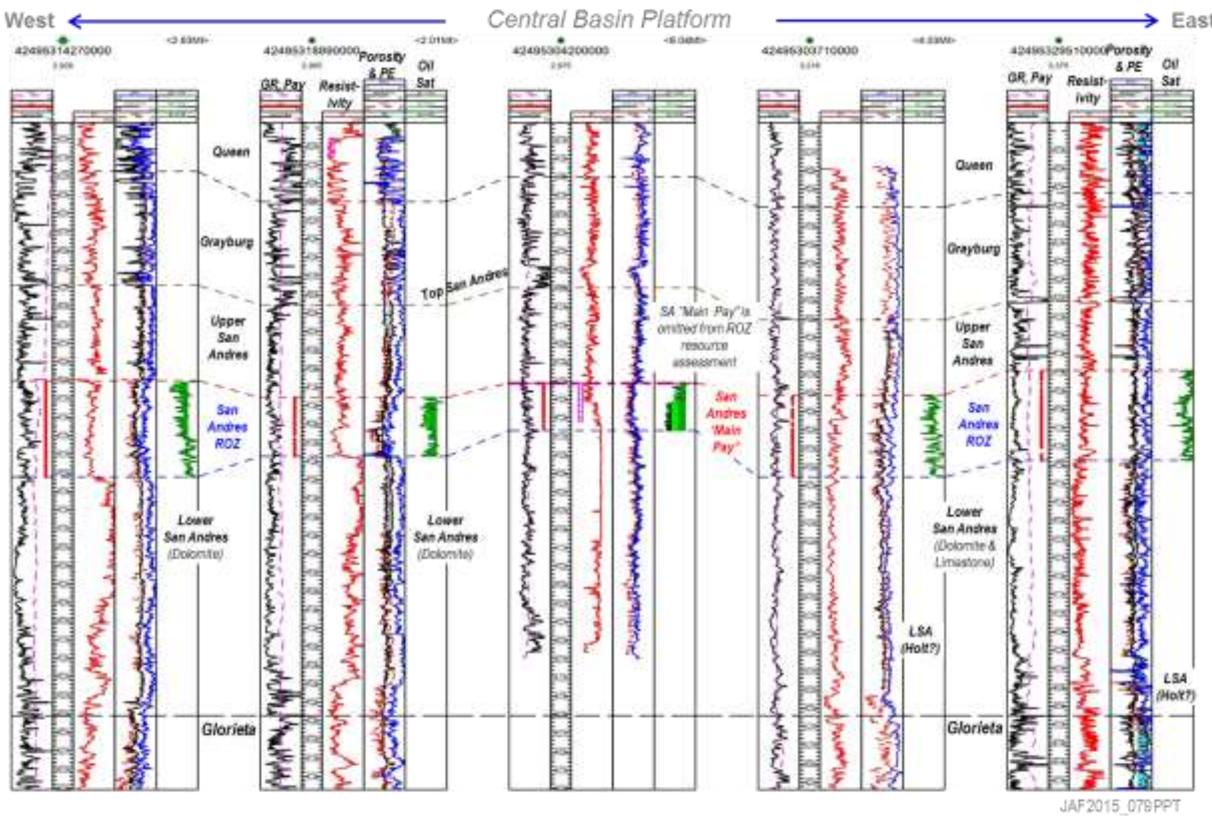


Log Analysis Parameters: Rw = 0.10; a = 1; m = 2.3; n = 3.4;

Porosity logs for cross-section wells are lithology-corrected density-neutron cross-plot porosity or sonic porosity. Gray shading indicates porosity less than 0.06. Photo electric (PE) log > 4 capture units shaded in bright blue.

Green shading in Track 4 indicates calculated So between 0.25 and 0.45. Vertical red bar in Track 1 = net pay indicator where ROZ "pay" has porosity >0.06; no Sor pay cutoff applied.

Figure 7.4G-4. Winkler County Cross-Section B-B'

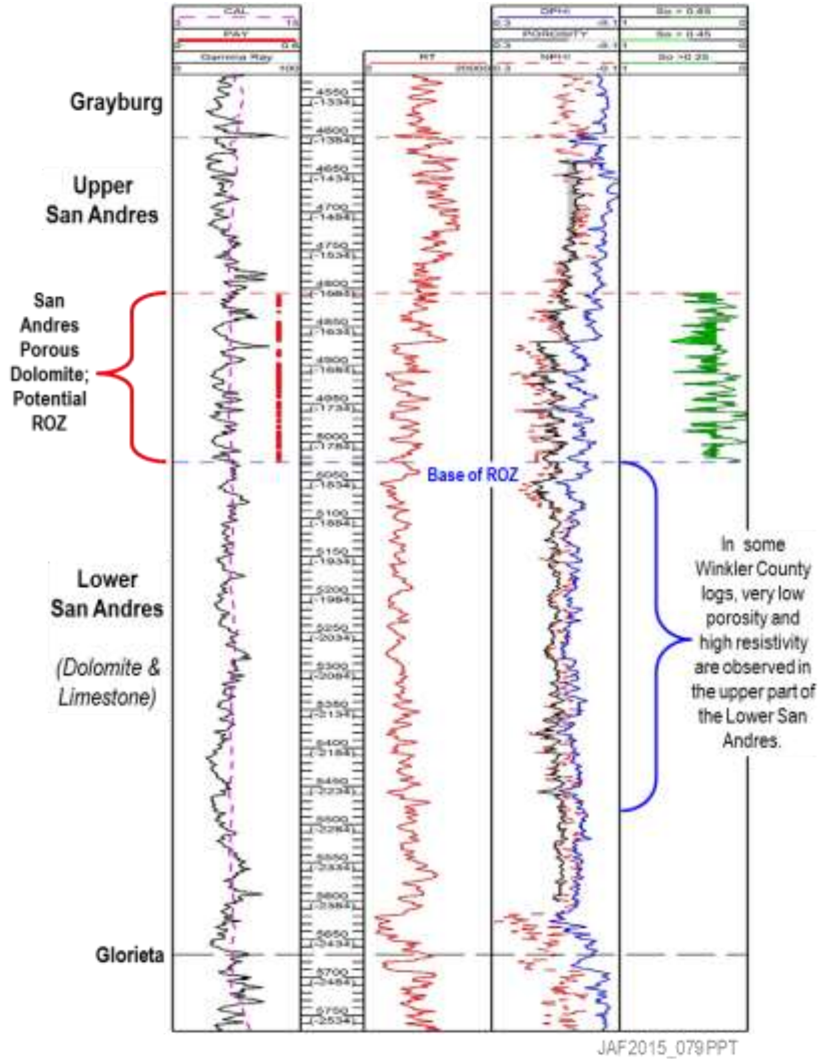


Log Analysis Parameters: Rw = 0.10; a = 1; m = 2.3; n = 3.4;

Porosity logs for cross-section wells are lithology-corrected density-neutron cross-plot porosity or sonic porosity. Gray shading indicates porosity less than 0.06. Photo electric (PE) log > 4 capture units shaded in bright blue.

Green shading in Track 4 indicates calculated So between 0.25 and 0.45. Vertical red bar in Track 1 = net pay indicator where ROZ "pay" has porosity >0.06; no Sor pay cutoff applied.

Figure 7.4G-5. Winkler County San Andres ROZ "Type Well" 42-495-30371; KB 3216



- Density and neutron porosity logs are corrected for dolomite & a cross-plot porosity is used to compute oil saturation.
- In Winkler Co., an additional correction may be applied to reduce the apparent neutron porosity response to the presence of gypsum.
- The sonic log is preferred for the oil saturation calculation if available.
- Cross-plot porosity is shown in black. Neutron porosity (limestone) shown in red. Density porosity (limestone) shown in blue.
- Note the overall thin-bedded log character of the San Andres porous dolomite.
- Lower San Andres generally has low porosity in Winkler County. Lithology (dolomite vs. limestone) can be uncertain from well logs alone.

Partitioning the ROZ “Fairway” Resource

The ROZ “fairway” in Winkler County is placed into two distinct partitions. Individual ROZ “fairway” resource assessments were undertaken for each of these two partitioned areas. The partitions are guided by current structure and prominent features of the Permian Basin within Winkler County.

- Partition #1. Covers a 172,000 acre (269 mi^2) area of central Winkler County on the Central Basin Platform. No area has been excluded from Partition #1.

- Partition #2. Covers a 170,800 acre (267 mi^2) area of eastern Winkler County in the Central Basin Platform. No area has been excluded from Partition #2.

Partition #1, located in central Winkler County, covers a “fairway” area of 172,000 acres (269 mi^2) in the southern portion of the Permian Basin.

- The partition is located within the currently defined ROZ “fairway” boundary.
- The resource assessment for Partition #1 used five distinct log analysis-based reservoir properties data points.
- No area has been excluded from Partition #1.

The ROZ “type well” and the average reservoir properties for the five San Andres ROZ wells in Partition #1 of Winkler County are shown in Table 7.4-15.

Table 7.4-15. Average Reservoir Properties Central Winkler County

	Average Reservoir Properties	
	ROZ "Type Well"	ROZ Resource
	Higher Quality	Higher Quality
Depth to top, (ft)	4,130	4,060
Gross Thickness (ft)	159	225
Net Pay (ft)	131	177
Avg. Porosity (fraction)	0.117	0.099
Avg. Oil Saturation (fraction)	0.42	0.37
Formation Volume Factor	1.40	1.40
OIP (B/AF, for net pay)	272	203
OIP (B/Acre)	35,700	35,900

Partition #1: Central Winkler County

The ROZ interval in Partition #1 of Winkler County contains 6.18 billion barrels of oil in-place (OIP). The ROZ resource in Partition #1 is higher quality (porosity greater than 8% and oil saturation greater than 25%). All five of the log-based ROZ data points meet the higher resource quality criteria.

- Higher quality ROZ resource - - 6.18 billion barrels
- Lower quality ROZ resource - - none

Partition #2: Eastern Winkler County

Partition #2, located in eastern Winkler County, covers an area of 170,800 acres (267 mi^2) of the Central Basin Platform in the southern portion of the Permian Basin.

- The partition is located to the east of the currently defined San Andres ROZ "fairway".
- The resource assessment for Partition #2 used 7 distinct log analysis-based reservoir properties data points.
- The partition area does not exclude any major San Andres oil fields.

The ROZ "type wells" and average reservoir properties for the seven San Andres ROZ wells in Partition #2 of Winkler County are shown in Table 7.4-16.:

Table 7.4-16. Average Reservoir Properties Eastern Winkler County

	Average Reservoir Properties			
	ROZ "Type Wells"		ROZ Resource	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Depth to top (ft)	4,380	4,810	4,350	4,770
Gross Thickness (ft)	188	299	185	244
Net Pay (ft)	159	160	136	136
Avg. Porosity (fraction)	0.099	0.110	0.099	0.101
Avg. Oil Saturation (fraction)	0.28	0.23	0.33	0.20
Formation Volume Factors	1.40	1.40	1.40	1.40
OIP (B/AF, for net pay)	154	140	181	112
OIP (B/Acre)	24,400	22,430	24,600	15,200

The ROZ interval in Partition #2 of Winkler County contains 3.29 billion barrels of oil in-place (OIP). Approximately half of the ROZ resource in Partition #2 is higher quality. Three of the seven log-based ROZ data points meet the higher quality criteria (porosity greater than 8% and oil saturation greater than 25%).

- Higher quality ROZ resource - - 1.80 billion barrels
- Lower quality ROZ resource - - 1.49 billion barrels

7.4.4H San Andres Residual Oil Zone Resource: Ector County

Ector County, Texas contains 6.95 billion barrels of oil in-place in the residual oil zone (ROZ) outside the limits and structural closure of the existing oil fields in the county. Ector County has been divided into three distinct partitions, with oil in-place and resource quality values provided for each partition, as shown in Table 7.4-17.

Table 7.4-17. Residual Oil Zone Resource: Ector County

Partitions	**ROZ Resource** (Billion Barrels)		
	Higher Quality	**Lower Quality**	**Total**
#1	0.23	0.54	0.77
#2	1.81	0.43	2.24
#3	3.51	0.43	3.94
Total	**5.55**	**1.40**	**6.95**

A significant portion of the ROZ oil in-place resource in the Central Basin Platform (western) portion of Ector County, 5.55 billion barrels, has higher quality reservoir properties (porosity greater than 8% and oil saturation equal to or greater than 25%).

The remainder of the ROZ oil in-place resource, 1.40 billion barrels, has lower quality reservoir properties (porosity equal to or less than 8% and oil saturation of less than 25%). However, each of the three partitions of Ector County contains both higher and lower quality ROZ oil in-place resources.

Geographic and Geologic Setting

Ector County, Texas covers a 577,000 acre (902 mi^2) area. Approximately eighty percent of the county is on the Central Basin Platform. The remainder of the area is east of this prominent Permian Basin feature, but within the extent of the southward prograding Lower and Middle San Andres shelf margins.

The county contains numerous large San Andres oil fields - - Cowden North and South, Foster, Goldsmith, Harper, Penwell and TXL, among others. The ROZ resource below these and other existing San Andres oil fields has been excluded from the resource assessment of the San Andres ROZ “fairway” in Ector County.

The currently mapped outlines of the San Andres ROZ “fairway” include the east-central portion of Ector County, with the eastern and western-portions of the county deemed to be outside of the “fairway” boundaries.

A total of 31 logs that penetrate the San Andres ROZ were evaluated to provide the primary information for this Ector County study. Of these, 22 wells were selected for the resource assessment. Additional raster logs and mud logs were reviewed to guide the acquisition and interpretation of the digital log data.

Ector County Cross-Sections and “Type Well”

Figure 7.4H-1, the Ector County map shows: (1) the location of 31 study wells; (2) the four ROZ “fairway” partitions; (3) the boundaries of the currently defined ROZ “fairway”; (4) the outline of the Central Basin Platform; and (5) an area excluded from the San Andres ROZ “fairways” resource assessment.   The boundaries of Partition 2 are aligned with the boundaries of the mapped ROZ “fairway” in Ector County. The map also shows location of the major San Andres oil fields excluded from the ROZ “fairway” assessment.

Figure 7.4H-2 shows two stratigraphic “cross-sections illustrating the correlation of the San Andres ROZ interval within Ector County. Figure 4-4-3 shows the Ector County Cross-Section A-A’ and Figure 4-4-4 Ector County Cross-Section B-B’.

Figure 7.4H-5 shows logs for Ector County San Andres ROZ “Type Well” 42-135-31419, KB 2,989.

Figure 7.4H-1. Ector County Cross-Sections and "Type Well"

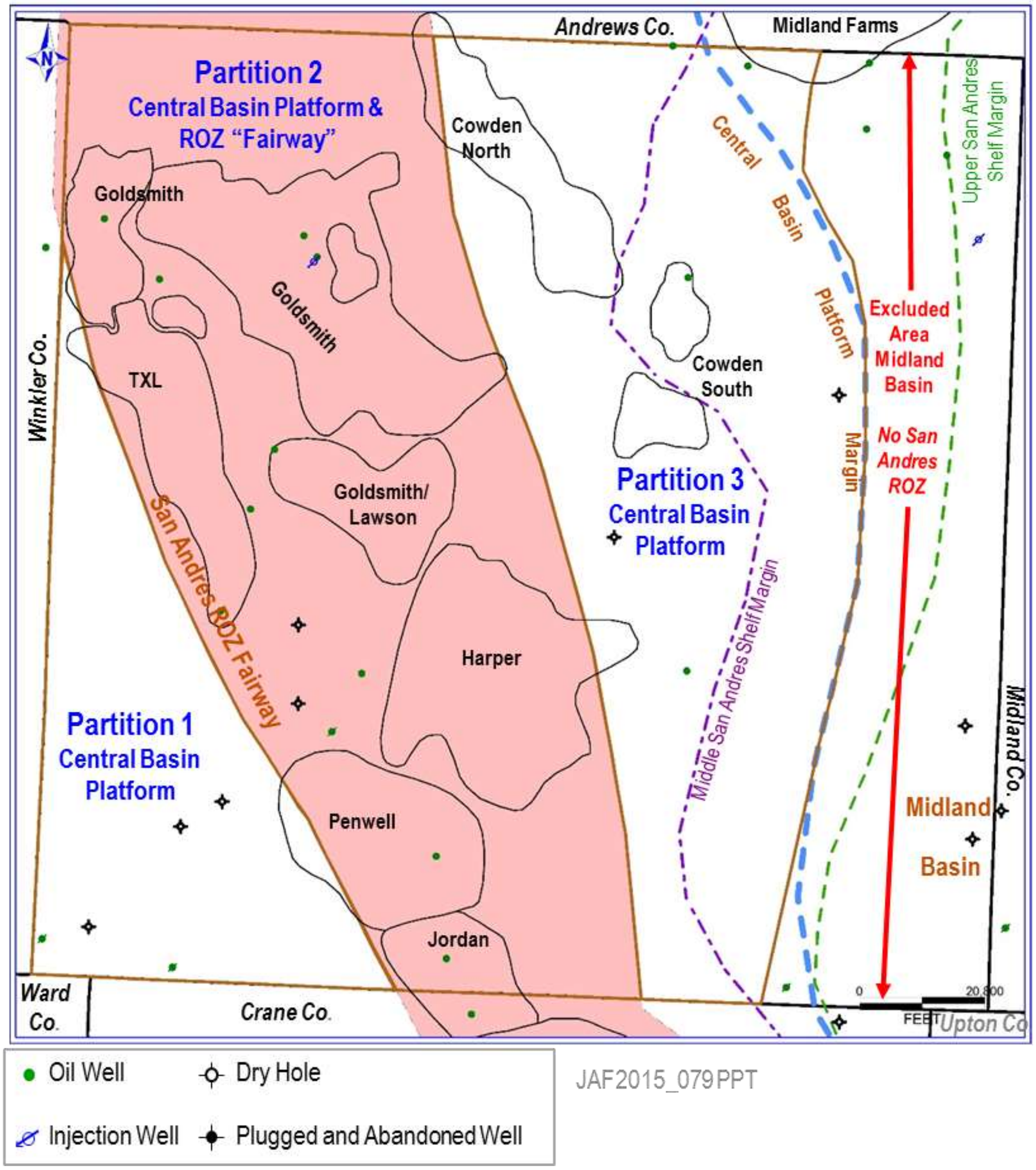


Figure 7.4H-2. Ector County Partitions and Study Wells

Two stratigraphic "cross-sections illustrate the correlation of the San Andres ROZ interval within Ector County.

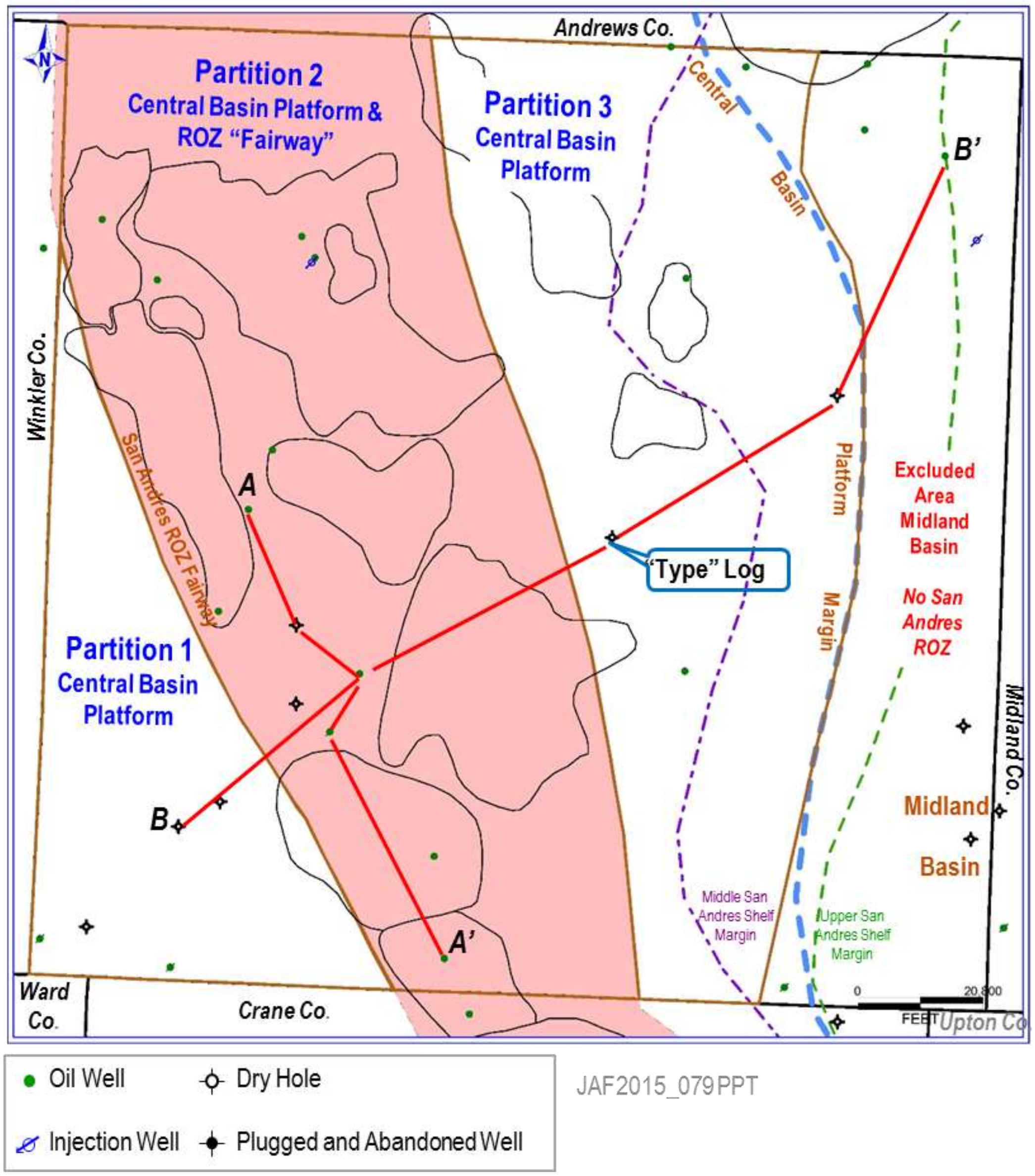
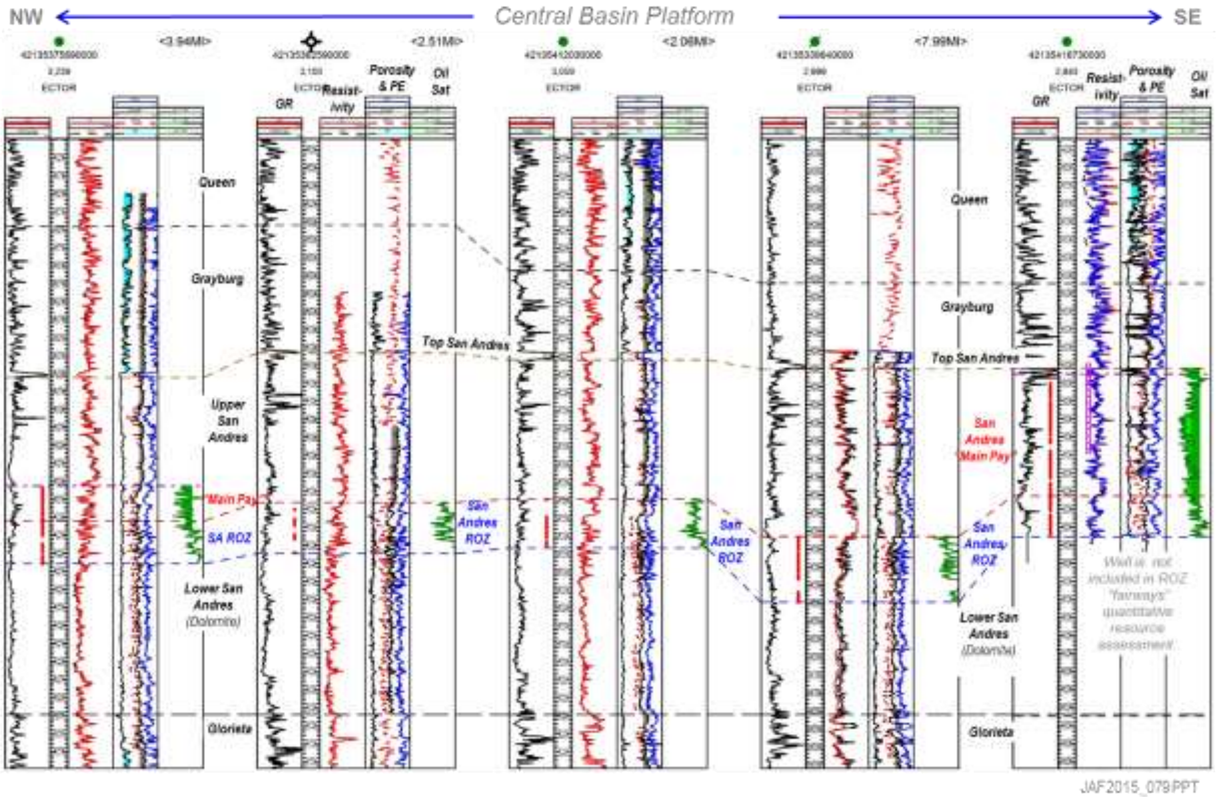


Figure 7.4H-3. Ector County Cross-Section A-A'

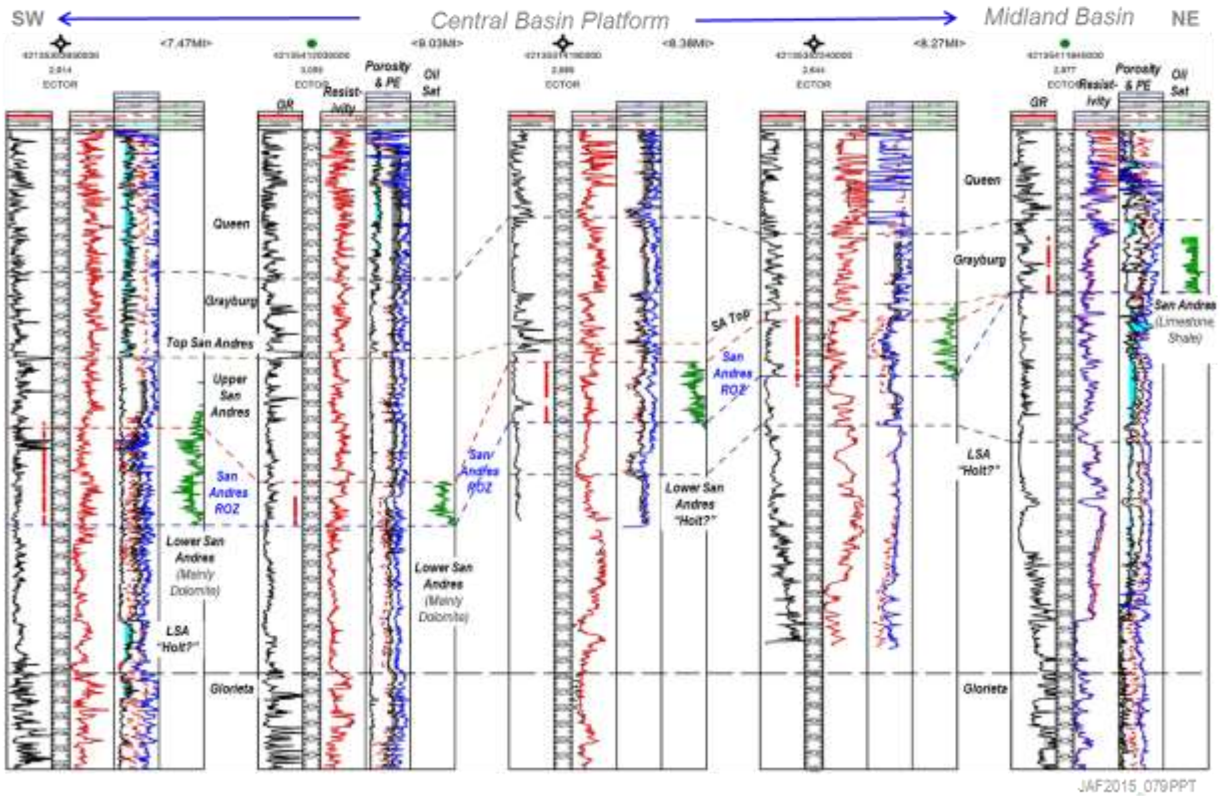


Log Analysis Parameters: Rw = 0.07; a = 1; m = 2.3; n = 3.4; San Andres apparent "Main Pay" intervals are excluded from ROZ "fairways" resource assessment.

All porosity logs for cross-section wells are density-neutron cross-plot porosity or lithology-corrected neutron porosity. Gray shading indicates porosity less than 0.06. Photo electric (PE) log > 4 capture units shaded in bright blue.

Green shading in Track 4 indicates calculated So between 0.25 and 0.45. Vertical red bar in Track 1 = net pay indicator where ROZ "pay" has porosity >0.06; no Sor pay cutoff applied.

Figure 7.4H-4. Ector County Cross-Section B-B'

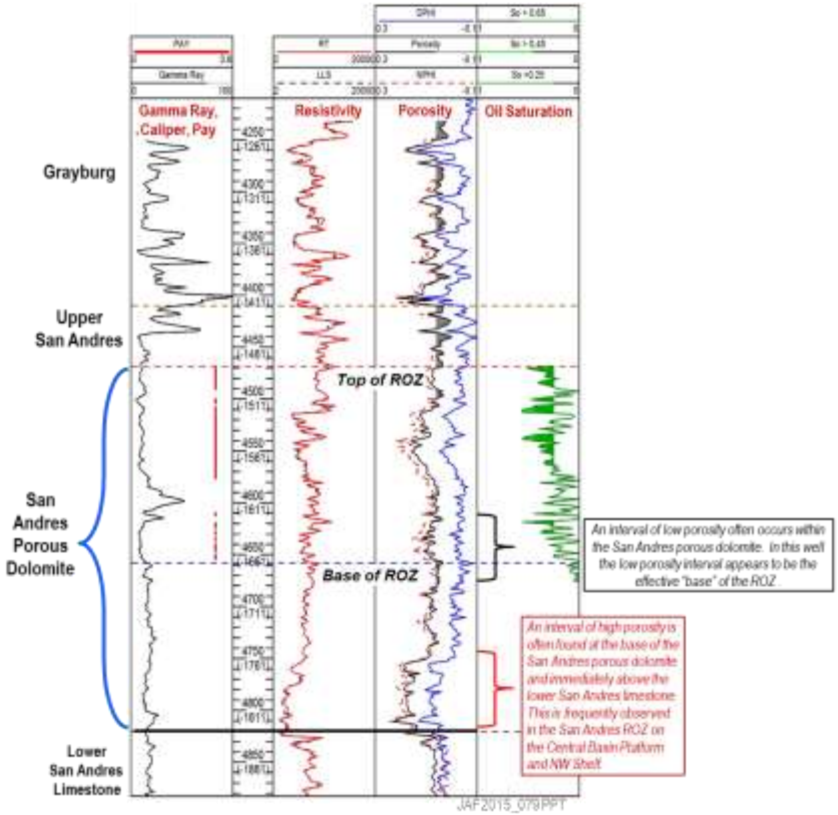


Log Analysis Parameters for Central Basin Platform wells: Rw = 0.07; a = 1; m = 2.3; n = 3.0;
Log Analysis Parameters for Midland Basin wells: Rw = 0.055; a=1; m=2.3; n=3.0

All porosity logs for cross-section wells are density-neutron cross-plot porosity or lithology-corrected neutron porosity. Gray shading indicates porosity less than 0.06. Photo electric (PE) log > 4 capture units shaded in bright blue.

Green shading in Track 4 indicates calculated So between 0.25 and 0.45. Vertical red bar in Track 1 = net pay indicator where ROZ "pay" has porosity >0.06; no Sor pay cutoff applied.

Figure 7.4H-5. Ector County San Andres ROZ "Type Well" 42-135-31419, KB 2,989



- Density and neutron porosity logs are corrected for dolomite & a cross-plot porosity is used to compute oil saturation.
- Final cross-plot porosity is shown in black. Uncorrected neutron porosity (limestone) is shown in red. Uncorrected density porosity (limestone) is shown in blue.
- Calculated porosity less than 6 percent is shaded in gray.
- Archie parameters for calculating water saturation: Rw = .07 ohm-m; 'm' = 2.3, 'a' = 1; 'n' = 3.4
- Total 'net pay' of ROZ = 146' (porosity > 0.06)
- Average porosity of net pay = 0.095
- Average oil saturation of net pay = 0.30
- ROZ in this well is characterized as "high quality."

Partitioning the ROZ "Fairway" Resource

The San Andres ROZ "fairway" in Ector County is partitioned into three distinct areas, with individual ROZ "fairway" resource assessments were undertaken for each of the three partitioned areas. The partitions are guided by current structure and prominent features of the Permian Basin within each county. A portion of eastern Ector County encompassing 106,900 acres has been excluded from the resource assessment because a San Andres ROZ is not present.

- ***Partition #1.*** Covers a 73,800 acre (115 mi^2) area of southwestern Ector County. No area has been excluded from this partition.

- ***Partition #2***. Covers a 224,600 acre (351 mi^2) area of west-central Ector County on the Central Basin Platform. The Goldsmith (21,200 acres), Harper (9,700 acres), Jordon (12,100 acres), Lawson (4,600 acres), Penwell (15,700 acres) and TXL (8,500 acres) oil fields covering 71,800 acres (112 mi^2), have been excluded from the resource assessment area of Partition #2, leaving a "fairway" area of 152,800 acres (239 mi^2).

- ***Partition #3.*** Covers a 171,700 acre (268 mi^2) area of central Ector County on the Central Basin Platform. Four large San Andres oil fields - - Cowden North (15,500 acres), Cowden South (20,000 acres), Foster (8,600 acres) and Johnson (6,000 acres) have been excluded from the "fairway" resource assessment for Partition #3 leaving a "fairway" of 121,700 acres (190 mi^2).

Partition #1, located in southeastern Ector County, covers a San Andres ROZ "fairway" area of 73,800 acres (115 mi^2) in the Midland Basin portion of the Permian Basin.

- Partition #1 is located to the southeast of the currently established San Andres ROZ "fairway" boundary.

- The resource assessment for Partition #1 used 5 distinct log analysis-based reservoir properties data points.

- The partition does not contain any large San Andres oil fields.

Partition #1: Southwestern Ector County

The ROZ "type wells" and average reservoir properties for the five San Andres ROZ "fairway" wells in Partition #1 of Ector County are shown in Table 7.4-18.

Table 7.4-18. Average Reservoir Properties Southwestern Ector County

	Average Reservoir Properties			
	ROZ "Type Wells"		ROZ Resource	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Depth to Top (ft)	4,322	3,950	4,322	4,146
Gross Thickness (ft)	213	184	213	170
Net Pay (ft)	96	83	96	83
Avg. Porosity (fraction)	0.093	0.128	0.093	0.109
Avg. Oil Saturation (fraction)	0.27	0.18	0.27	0.16
Formation Volume Factor	1.22	1.22	1.22	1.22
OIP (B/AF, for net pay)	160	147	160	111
OIP (B/Acre)	15,300	12,200	15,300	9,300

The ROZ interval in Partition #1 of Ector County contains 0.77 billion barrels of oil in-place (OIP). The bulk of the ROZ resource in Partition #1 is lower quality. Four of the five log-based ROZ data points fall below the higher resource quality criteria (porosity greater than 8% and oil saturation greater than 25%).

- Higher quality ROZ resource - - 0.23 billion barrels
- Lower quality ROZ resource - - 0.54 billion barrels

Partition #2: West-Central Ector County

Partition #2, located in west-central Ector County, covers a San Andres ROZ "fairway" area of 152,800 acres (239 mi^2) on the southern portion of the Central Basin Platform, Permian Basin.

- The partition is within the currently defined San Andres ROZ "fairway" boundary.
- The resource assessment for Partition #2 used 10 distinct log analysis-based reservoir properties data points.
- The partition excludes the Goldsmith, Harper, Jordan, Lawson, Penwell and TXL oil fields covering 71,800 acres (112 mi^2).

The ROZ "type wells" and average reservoir properties for the ten San Andres ROZ wells in Partition #2 of Ector County are shown in Table 7.4-19.

Table 7.4-19. Average Reservoir Properties West-Central Ector County

	Average Reservoir Properties			
	ROZ "Type Wells"		ROZ Resource	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Depth to Top (ft)	4,280	4,490	4,250	4,590
Gross Thickness (ft)	108	162	135	141
Net Pay (ft)	93	84	90	75
Avg. Porosity (fraction)	0.109	0.102	0.094	0.096
Avg. Oil Saturation (fraction)	0.42	0.20	0.35	0.23
Formation Volume Factor	1.36	1.36	1.36	1.36
OIP (B/AF, for net pay)	257	116	186	124
OIP (B/Acre)	23,800	9,800	16,800	9,300

The San Andres ROZ interval in Partition #1 of Ector County contains 2.24 billion barrels of oil in-place (OIP). The bulk of the San Andres ROZ resource in Partition #1 is higher quality (porosity greater than 8% and oil saturation greater than 25%). Seven of the ten log-based ROZ data points meet the higher resource quality criteria.

- Higher quality ROZ resource - - 1.81 billion barrels
- Lower quality ROZ resource - - 0.43 billion barrels

Partition #3: Central Ector County

Partition #3, located in central Ector County, covers a “fairway” area of 121,700 acres (190 mi^2) on the Central Basin Platform of the Permian Basin.

- The partition is located east of the currently defined San Andres ROZ “fairway”.
- The resource assessment for Partition #3 used 6 distinct log analysis-based reservoir properties data points.
- The partition excludes 50,000 acres (78 mi^2) under the Cowden, North and South, Foster and Johnson oil fields.

The ROZ “type wells” and average reservoir properties for the six San Andres ROZ wells in Partition #3 of Ector County are shown in Table 7.4-20.

Table 7.4-20. Average Reservoir Properties Central Ector County

	Average Reservoir Properties			
	ROZ "Type Wells"		ROZ Resource	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Depth to Top (ft)	4,260	4,830	4,470	4,940
Gross Thickness (ft)	322	253	278	240
Net Pay (ft)	259	74	195	109
Avg. Porosity (fraction)	0.104	0.100	0.100	0.110
Avg. Oil Saturation (fraction)	0.33	0.12	0.36	0.15
Formation Volume Factors	1.26	1.26	1.26	1.26
OIP (B/AF, for net pay)	211	74	222	102
OIP (B/Acre)	5,470	5,500	43,300	11,000

The ROZ interval in Partition #3 of Ector County contains 3.94 billion barrels of oil in-place (OIP). The bulk of ROZ resource in Partition #2 is higher quality. Three of the six log-based ROZ data points used in the resource assessment meet the higher quality criteria (porosity greater than 8% and oil saturation greater than 25%).

- Higher quality ROZ resource - - 3.51 billion barrels
- Lower quality ROZ resource - - 0.43 billion barrels

7.4 (I-L) San Andres Residual Oil Zone Resource: Southern Tier Counties

The three county area in the Southern Permian Basin - - Ward, Crane and Upton counties, Texas - - contains 19.18 billion barrels of oil in-place in the residual oil zone (ROZ), outside the limits and structural closure of the existing oil fields in these counties.

This three county area has been divided into four distinct partitions, with oil in-place and resource quality values provided for each partition, as shown in Table 7.4-21.

Table 7.4-21. Residual Oil Zone Resources: Three Southern Tier Counties

Partitions	ROZ Resources (Billion Barrels)		
	Higher Quality	**Lower Quality**	**Total**
#1 (Ward Co.)	4.13	4.18	8.31
#2 (Crane Co.)	2.13	2.34	4.47
#3 (Crane Co.)	2.41	0.67	3.08
#4 (Upton Co.)	-	3.32	3.32
Total	**8.67**	**10.51**	**19.18**

Quality of Residual Oil Zone Resources: Three Southern Tier Counties

Nearly half of the ROZ oil in-place resource in the three Southern Tier counties, 8.67 billion barrels, has higher quality reservoir properties (porosity greater than 8% and oil saturation equal to or greater than 25%). The higher quality ROZ resources are concentrated in a relatively small, 327,000 acre area, encompassing 12% of the land area in these three counties.

The remainder of the ROZ oil in-place resource in these three counties, 10.51 billion barrels, has lower quality reservoir properties (porosity equal to or less than 8% and oil saturation of less than 25%). The lower quality ROZ resource is deposited in a 533,000 acre area, encompassing 29% of the land area in these three counties.

Geographic and Geologic Setting

The total land area of the three Southern Tier counties of the Permian Basin (W. Texas) is about 1,833,000 acres (2,864 mi^2). Within these counties, the total area assessed for the San Andres ROZ “fairway” resource covers 760,000 acres (1,188 sq. mi^2).

The currently mapped outlines of the ROZ “fairway” encompasses the eastern portion of Ward County with approximately 296,000 acres (463 mi^2) in the western portion of the county in the Delaware Basin excluded from the ROZ resource assessment because the area is beyond the limits of San Andres deposition.

Also excluded are the Midland Basin portions of Crane County (8,000 acres; 12 mi2) and Upton County (606,000 acres; 947 mi^2) because the porous San Andres dolomite was found to be either very thin or absent in these areas.

The areas underlying the structural closure of existing San Andres oil fields, equaling approximately 163,000 acres (255 mi^2), were also excluded from the San Andres ROZ “fairways” resource assessment.

Distribution of the Three Southern Tier Counties Land Area

Only a relatively small portion of the 1,833,000 acre (2,864 mi^2) land area holds the 8.67 billion barrels of higher quality ROZ oil in-place, as shown in Table 7.4-22.

Table 7.4-22. Distribution of the Three Southern Tier Counties Land Area

County	Total Area	Outside Study Boundaries	Below Existing Oil Fields	Sub-Total Area	Quality Area	
					Higher	Lower
	(Acres)	(Acres)	(Acres)	(Acres)	(Acres)	(Acres)
Ward	536,000	(296,000)	(1,000)	239,000	87,000	152,000
N. Crane	256,000	(8,000)	(113,000)	135,000	34,000	101,000
S. Crane	246,000	-	(35,000)	211,000	106,000	105,000
Upton	795,000	(606,000)	(14,000)	175,000	-	175,000
Total	1,833,000	(910,000)	(163,000)	760,000	227,000	533,000
Percent	**100%**	**(50%)**	**(9%)**	**41%**	**12%**	**29%**

- Approximately half of the acreage in these Three Southern Tier counties is excluded because the area is beyond the limits of San Andres deposition or the presence of the San Andres ROZ is uncertain due to lack of data.

- An additional 9% of the acreage is excluded because the area is underneath the structural limits of existing major San Andres oil fields.

- Of the remaining area (760,000 acres), about one-third (12% of total area) is assessed as higher quality with two-thirds (29% of total area) assessed as lower quality.

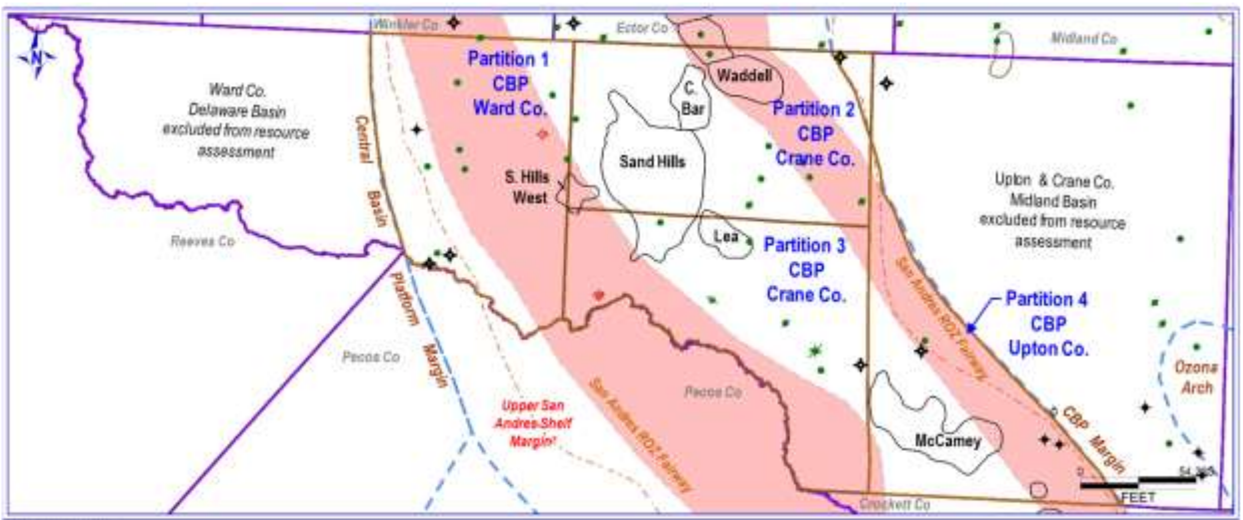
A total of 45 logs that penetrate the San Andres ROZ were evaluated to provide the primary information for this three Southern Tier county ROZ “fairway” resource study. From this initial data set, 27 wells were selected for the quantitative portion of the resource assessment. Additional raster logs and mud logs were reviewed to guide the acquisition and interpretation of the digital log data. The San Andres Fm of the Sand Hills oil field, located in central Crane County, was used to help calibrate the log data for the MPZ with previously established reservoir data for the MPZ.

Figure 7.4I-1 shows the Three Southern Tier Counties Partitions and Study Wells map. Figure 7.4I-2 shows the Three Southern Tier Counties Cross-Sections map.

Figure 7.4I-3 shows the Southern Tier Counties Cross-Section A-A' and Figure 4-5-4 shows the Southern Tier Counties Cross-Section B-B'.

Figure 7.4I-5 shows the logs for the Three Southern Tier Counties San Andres ROZ "Type Well" 42-475-31608, K.B. 2594

Figure 7.4I-1. Three Southern Tier Counties Partitions and Study Wells

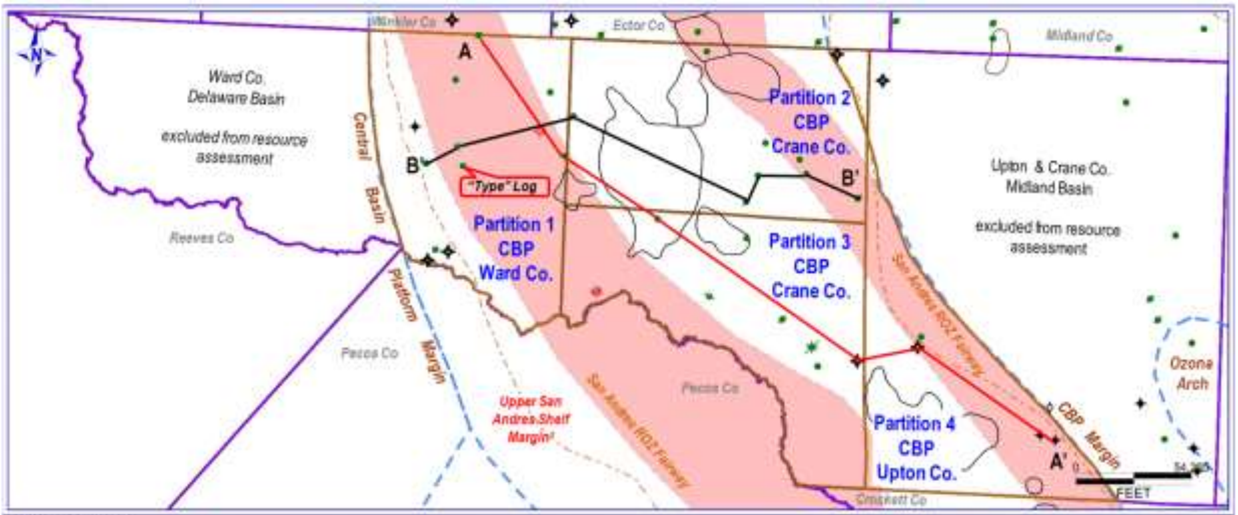


The three county map shows: (1) the location of 45 study wells; (2) the ROZ four "fairway" partitions; (3) the boundaries of the currently defined ROZ "fairway".

The map shows the approximate positions of the western Central Basin Platform (CBP) edge during late San Andres deposition, as well as the eastern and western margins of the CBP and the western portion of the Midland Basin.

The map also shows location of the major San Andres oil fields and the portions of Ward, Crane and Upton counties excluded from the ROZ "fairway" assessment.

Figure 7.4I-2. Three Southern Tier Counties Cross-Sections



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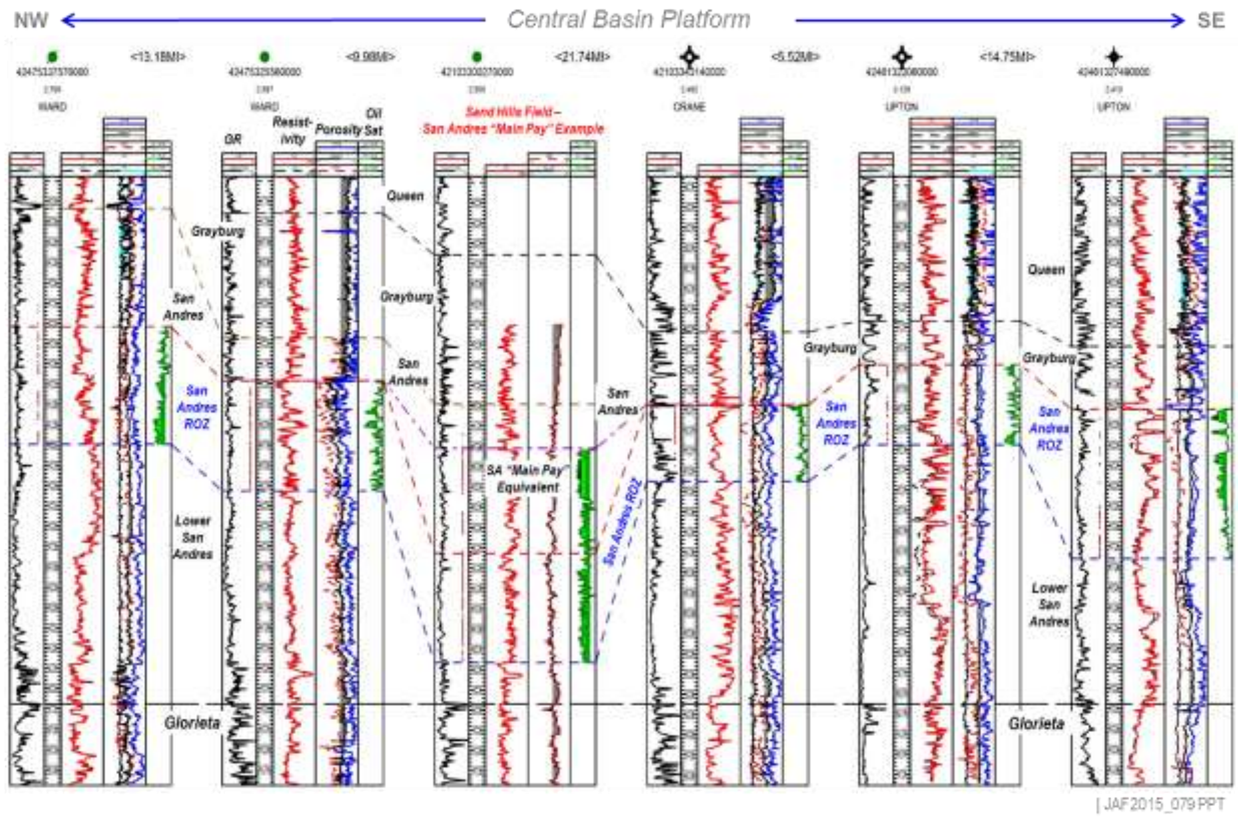
Two stratigraphic cross-sections were created to correlate the ROZ interval within the three Southern Tier counties.

The cross-sections are hung on the Glorieta top and show the entire San Andres and Grayburg Formations.

Several sources helped to guide the stratigraphic correlations including well records and publications highlighting the Grayburg/San Andres intervals in Crane and Upton counties.

Figure 7.4I-3. Southern Tier Counties Cross-Section A-A'



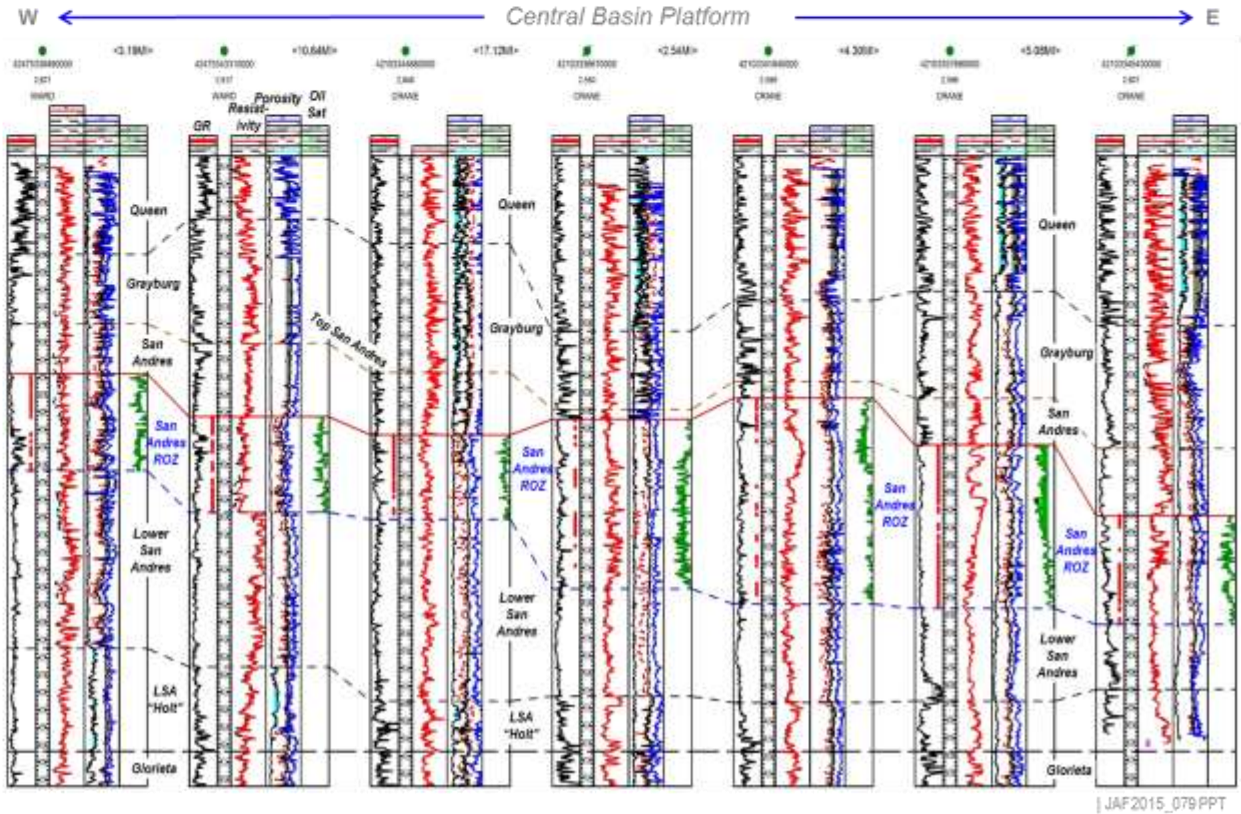
Log Analysis Parameters: Rw = 0.125; a = 1; m = 2.3; n = 3.4; Used Rw=0.195 for selected wells in southern Crane Co.

All porosity logs for cross-section wells are density-neutron cross-plot porosity or lithology-corrected neutron porosity. Gray shading indicates porosity less than 0.06.

Green shading in Track 4 indicates calculated So between 0.25 and 0.45.

Vertical red bar in Track 1 = net pay indicator where ROZ "pay" has porosity >0.06 ; no Sor pay cutoff applied

Figure 7.4I-4. Southern Tier Counties Cross-Section B-B'



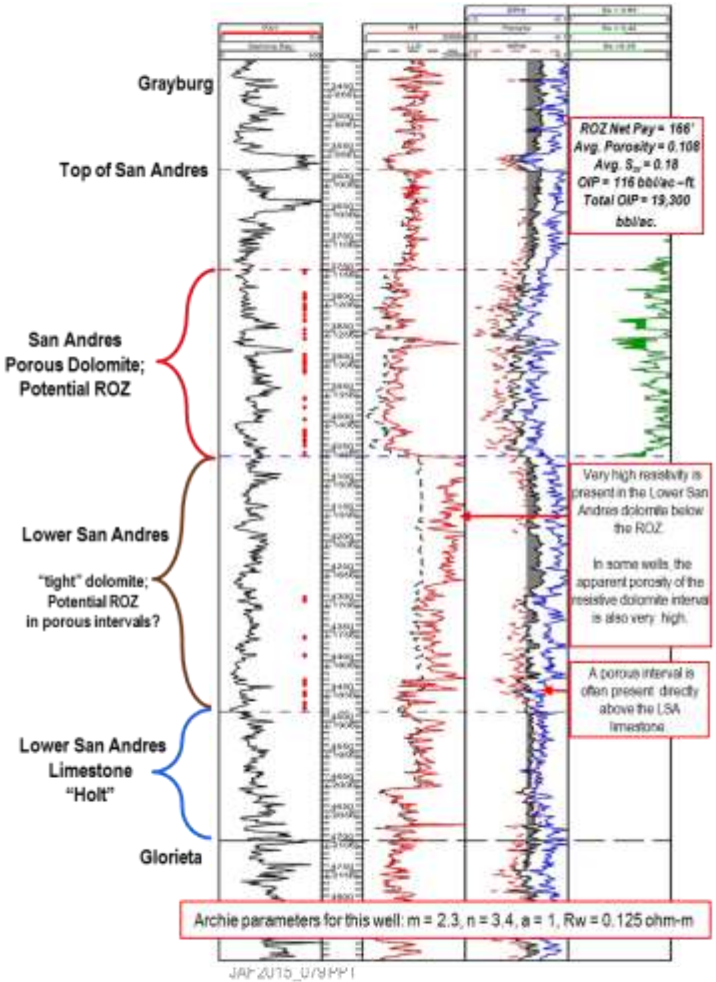
Log Analysis Parameters: Rw = 0.125; a = 1; m = 2.3; n = 3.4;

All porosity logs for cross-section wells are density-neutron cross-plot porosity or lithology-corrected neutron porosity. Gray shading indicates porosity less than 0.06.

Green shading in Track 4 indicates calculated So between 0.25 and 0.45.

Vertical red bar in Track 1 = net pay indicator where ROZ "pay" has porosity >0.06 ; no Sor pay cutoff applied

Figure 7.4I-5. Three Southern Tier Counties San Andres ROZ "Type Well" 42-475-31608, K.B. 2594



- This well is typical of the San Andres Fm observed in the study wells in the Southern Tier counties.
- The Main Pay Zone (if present) and ROZ are developed at or near the top of the San Andres.
- The Grayburg and San Andres are difficult to discriminate based on well logs. The San Andres top shown here is from the well record.
- Porosity is developed in fairly thin beds that appear to be interbedded with shale or siltstone.
- Density and neutron porosity logs are corrected for dolomite. A cross-plot porosity (black) is used to compute oil saturation. Porosity < 0.06 is shaded gray.
- To illustrate lithology, uncorrected neutron porosity (limestone) is shown in red; uncorrected density porosity (limestone) is shown in blue.
- Gypsum and elemental sulfur may affect neutron and density porosity. Sonic porosity is used if available; otherwise additional corrections have been applied to the neutron and density logs.
- Complex lithology may also be affecting the resistivity log response in the Lower San Andres. Unusually high resistivity zones are omitted from the ROZ analysis.

Partitioning the ROZ "Fairway" Resource

The ROZ "fairway" in the Three Southern Tier counties is partitioned into four distinct areas. Individual ROZ "fairway" resource assessments were undertaken for each of the two partitioned areas. The partitions are guided by current structure and prominent features of the Permian Basin within each county.

- Partition #1 (Ward Co.). Covers a 239,000 acre (373 mi^2) area of central and eastern Ward County. A portion of the Sand Hills West oil field with approximately 1,000 acres (2 mi^2) has been excluded from Partition #1.

- Partition #2 (Crane Co.). Covers a 135,000 acre (211 mi^2) area of northern Crane County. Excludes 113,000 areas (177 mi^2) underneath existing oilfields as well as about 8,000 acres (12 mi^2) of NE Crane Co. where the San Andres dolomite is absent.

- Partition #3 (Crane Co.). Covers a 211,000 acre (330 mi^2) area of southern Crane County. Excludes 35,000 acres (55 mi^2) underneath existing oil fields.

- Partition #4. (Upton Co.). Covers a 175,000 acre (274 mi^2) area of southwestern Upton County. Excludes 14,000 acres (22 mi^2) underneath existing oil fields within the San Andres ROZ "fairway", as well as the remaining 606,000 acres (945 mi^2) of Upton County where porous San Andres dolomite is thin or absent.

7.4J Partition #1: Central and Eastern Ward County

Partition #1, located in central and eastern Ward County, covers a ROZ "fairway" area of 239,000 acres (373 mi^2) in the southern tier of the Permian Basin.

- The partition is located on the Central Basin Platform and contains the currently defined ROZ "fairway" limits as well as a less defined area west of the "fairway."

- The resource assessment for Partition #1 used 11 distinct log analysis-based reservoir properties data points.

- The ROZ "fairway" acreage in Partition #1 excludes a portion of the area underneath the Sand Hills West oil field of 1,000 acres (2 mi^2).

The ROZ "type wells" and average reservoir properties for the eleven San Andres ROZ wells in Partition #1 of Ward County are shown in Table 7.4-23.

Table 7.4-23. Average Reservoir Properties Partition #1: Central and Eastern Ward County

	Average Reservoir Properties			
	ROZ "Type Wells"		ROZ Resource	
	Higher Quality*	Lower Quality**	Higher Quality	Lower Quality
Depth to Top (ft)	3,410	3,770	3,490	3,560
Gross Thickness (ft)	357	273	321	435
Net Pay (ft)	228	158	215	209
Avg. Porosity (fraction)	0.116	0.124	0.116	0.105
Avg. Oil Saturation (fraction)	0.30	0.23	0.32	0.21
Formation Volume Factor	1.30	1.30	1.30	1.30
OIP (B/AF, for net pay)	208	170	222	132
OIP (B/Acre)	47,400	26,900	47,700	27,600

* Well ID for Partition 1 Higher Quality ROZ "Type" Well: 42-475-33649
** Well ID for Partition 1 Lower Quality ROZ "Type" Well: 42-475-34331

The ROZ interval in Partition #1 (Ward County) contains 8.31 billion barrels of oil in-place (OIP). Approximately half of the ROZ resource in Partition #1 is higher quality (porosity greater than 8% and oil saturation greater than 25%). Four of the eleven log-based ROZ data points meet the higher resource quality criteria.

- Higher quality ROZ resource - - 4.13 billion barrels
- Lower quality ROZ resource - - 4.18 billion barrels

7.4K Partition #2: Northern Crane County

Partition #2, located in northern Crane County, covers a ROZ "fairway" area of 135,000 acres (211 mi^2) in the southern tier of the Permian Basin.

- The partition is located on the Central Basin Platform and contains a portion of the currently defined ROZ “fairway”.

- The resource assessment for Partition #2 used 7 distinct log analysis-based reservoir properties data points.

- The ROZ “fairway” acreage in Partition #1 excludes a series of major San Andres oil fields (Waddell, Sand Hills, Dune, and others) as well as the NE corner of Crane Co. where the San Andres Dolomite is absent, together encompassing 121,000 acres (189 mi^2).

The ROZ “type wells” and average reservoir properties for the seven San Andres ROZ wells in Partition #2 (Crane County) are shown in Table 7.4-24.

Table 7.4-24. Average Reservoir Properties Partition #2: Northern Crane County

	Average Reservoir Properties			
	ROZ “Type Wells”		ROZ Resource	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Depth to Top (ft)	3,720	3,730	3,570	3,480
Gross Thickness (ft)	446	411	621	611
Net Pay (ft)	340	194	315	227
Avg. Porosity (fraction)	0.085	0.091	0.098	0.087
Avg. Oil Saturation (fraction)	0.25	0.24	0.29	0.20
Formation Volume Factor	1.27	1.27	1.27	1.27
OIP (B/AF, for net pay)	145	133	174	106
OIP (B/Acre)	49,300	25,900	54,800	24,100

* Well ID for Partition 2 Higher Quality ROZ “Type” Well: 42-103-35769
** Well ID for Partition 2 Lower Quality ROZ “Type” Well: 42-103-36298

The ROZ interval in Partition #2 (Crane County) contains 4.47 billion barrels of oil in-place (OIP). Less than half of the ROZ resource in Partition #2 is higher quality (porosity greater than 8% and oil saturation greater than 25%). Two of the eight log-based ROZ data points meet the higher resource quality criteria.

- Higher quality ROZ resource - - 2.13 billion barrels
- Lower quality ROZ resource - - 2.34 billion barrels

Partition #3: Southern Crane County

Partition #3, located in southern Crane County, covers a ROZ "fairway" area of 211,000 acres (330 mi^2) in the southern tier of the Permian Basin.

- The partition contains a portion of the currently defined San Andres ROZ "fairway".
- The resource assessment for Partition #2 used 6 distinct log analysis-based reservoir properties data points.
- The ROZ "fairway" in Partition #3 excludes 35,000 acres underneath the structural closure of a series of major San Andres Fm oil fields (Lea, McElroy and Sand Hills).

The ROZ "type wells" and average reservoir properties for the six San Andres ROZ wells in Partition #3 (Crane County) are shown in Table 7.4-25.

Table 7.4-25. Average Reservoir Properties Partition #3: Southern Crane County

	Average Reservoir Properties			
	ROZ "Type Wells"		ROZ Resource	
	Higher Quality	Lower Quality	Higher Quality	Lower Quality
Depth to Top (ft)	2,390	2,270	2,580	2,380
Gross Thickness (ft)	189	177	178	153
Net Pay (ft)	101	57	96	47
Avg. Porosity (fraction)	0.111	0.099	0.107	0.105
Avg. Oil Saturation (fraction)	0.29	0.21	0.33	0.19
Formation Volume Factors	1.15	1.15	1.15	1.15
OIP (B/AF, for net pay)	217	140	238	135
OIP (B/Acre)	21,900	8,000	22,800	6,300

* Well ID for Partition 3 Higher Quality ROZ "Type" Well: 42-103-34314
** Well ID for Partition 3 Lower Quality ROZ "Type" Well: 42-103-30005

The ROZ interval in Partition #3 (Crane County) contains 3.08 billion barrels of oil in-place (OIP). The bulk of the ROZ resource in Partition #3 is higher quality. Three of the six log-based ROZ data points meet the higher quality criteria (porosity greater than 8% and oil saturation greater than 25%).

- Higher quality ROZ resource - - 2.41 billion barrels
- Lower quality ROZ resource - - 0.67 billion barrels

7.4L Partition #4: Western Upton County

Partition #4, located in western Upton County, covers a ROZ "fairway" area of 175,000 acres (274 mi^2) on the Central Basin Platform. (The remaining portion of Upton County in the Midland Basin is excluded from the ROZ "fairway" resource assessment.)

- The partition contains a small band of currently defined San Andres ROZ "fairway" in the southwestern portion of the partition.
- The resource assessment for Partition #4 used 3 distinct log analysis-based reservoir properties data points.
- The partition excludes the McCamey oil field covering 14,000 acres (22 mi^2).

The ROZ "type wells" and average reservoir properties for the three San Andres ROZ wells in Partition #4 (Upton County) are shown in Table 7.4-26.

Table 7.4-26. Average Reservoir Properties Partition #4: Western Upton County

	Average Reservoir Properties	
	ROZ "Type Wells"	ROZ Resource
	Lower Quality	Lower Quality
Depth to Top (ft)	3,860	3,450
Gross Thickness (ft)	462	506
Net Pay (ft)	109	133
Avg. Porosity (fraction)	0.078	0.075
Avg. Oil Saturation (fraction)	0.28	0.27
Formation Volume Factor	1.10	1.10
OIP (B/AF, for net pay)	154	142
OIP (B/Acre)	16,800	19,000

** Well ID for Partition 4 Lower Quality ROZ "Type" Well: 42-461-36810

The San Andres ROZ interval in Partition #4 (Upton County) contains 3.32 billion barrels of oil in-place (OIP). All of the San Andres ROZ resource in Partition #4 is lower quality (porosity lower than 8% and/or oil saturation lower than 25%). All three of the log-based ROZ data points meet the lower resource quality criteria.

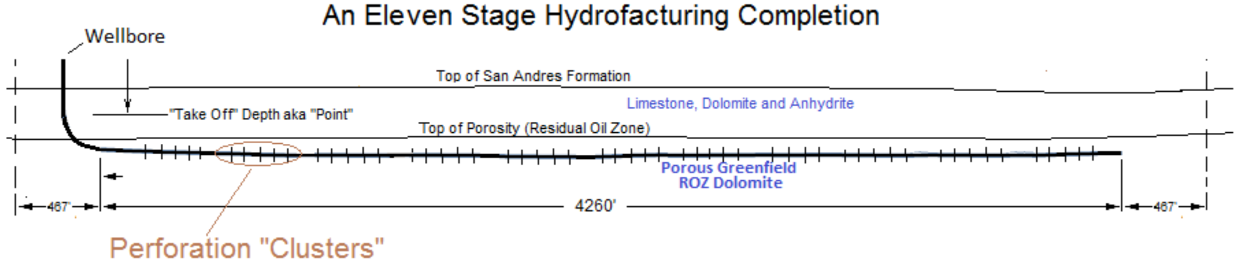
- Higher quality ROZ resource - - none
- Lower quality ROZ resource - - 3.32 billion barrels

Chapter 8: The Depressuring of the Upper ROZ Play

Author: L.S. Melzer, Melzer Consulting

As mentioned in the introduction to this report, a second commercial outgrowth of the ROZ characterization work, described in the previous chapters, came to light during the course of the project. This commercial deployment or "play" is a convergence of the new ROZ understandings and the technological developments associated with the horizontal well exploitation of the unconventional reservoirs. Figure 8.1 provides a cross sectional depiction of a well within the play.

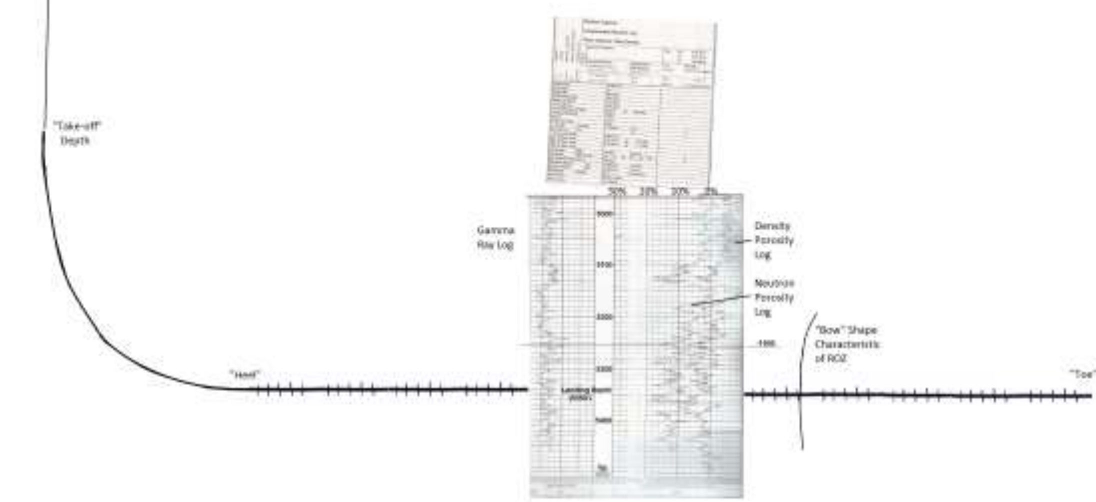
Figure 8.1
An Eleven Stage Hydrofacturing Completion



At the point in time of this report, the play is quite immature with only 30 or so wells and only a poor recognition of the actual mechanics of production involved. But, the results as presented herein, speak for themselves as to the commercial viability. For the ROZ researchers, what is quite evident is that the bulk of the oil being produced through the horizontal drilling and completion procedures is coming from the oil that is affixed to the rock in the form of the immobile oil of the ROZ. Undoubtedly, some wells draw some advantage from a mobile-component oil saturation near the top of the ROZ but the lack of primary recovery success in the areas of the play suggest that the contributions are very minor. The expansion of the producing horizontal "leg" portion of Fig. 8.1 is provided in Fig. 8.2 and superimposes the classic ROZ wireline log ROZ profile described in Chapter 2 and exhaustively used to identify and quantify ROZ resources in Chapter 7.

Mobilizing oil via gas solution "drive" is a well understood and fundamental principle of reservoir engineering. The concept of mobilizing immobile oil, like for a post-waterflood project, has generally been deferred to a category of enhanced oil recovery wherein an injectant is required to change the properties of the oil and release it into a flowstream to the producing wellbore. The common injectants include steam, chemicals and CO_2 although nitrogen and hydrocarbon gases are also used.

Figure 8.2
Example Depressuring ROZ Porosity Log



One of the attributes of a natural waterflood that is a key to the successful depressuring Upper ROZ (DUROZ) play is the knowledge that the natural waterflood occurs without a depressuring stage of primary production. That allows the gas in solution in the oil to remain unaltered unlike the case of an oil company's waterflood that generally follows a reservoir depressuring phase during primary production. And, with the gas remaining in solution, the first depressuring stage within a greenfield ROZ would be with the horizontal wellbore. For this reason, it will likely prove preferable to a brownfield one due to the risk that the ROZ has witnessed some amount of depressuring and loss of entrained gas from earlier primary producing phase of the overlying MPZ. As long as the gas is in solution in the residual oil, Fig. 8-3 illustrates conceptually how the process should work.

Figure 8.3
How Does ROZ Depressuring Work?

The procedures for depressuring the zone would necessarily require production of the mobile (formation water) phase in the reservoir. Considerable volumes of water have to be produced and the data base that has been gathered to date would suggest that, in our San Andres formation and mile long laterals, it takes 25-35 days of roughly 2000 barrels of water per day to reach the time and pressure in which oil begins to be produced. Table 8-1 is a recap of a number of wells that illustrate the time to first production and the intake pressures (submersible pumps are used) at that point in time. For the purposes of further discussion herein, we adopt the term 'bubble point' for that pressure threshold where oil begins to be rendered mobile.

Table 8.1
ROZ DEPRESURING WELLS: NORTH SHELF PERMIAN BASIN

Well	Initial Intake Pressure (psi)	First Oil Cut Intake Pressure (psi)	Lateral Length	# of Producing Days	Current Intake Pressure (psi)	Days Until First Oil Production	Cumulative Oil Production
#1	1745	1225	1 mile	393	340	26	61,004
#2	2120	1315	1 mile	378	455	31	70,022
#3	1700	1270	1 mile	195	735	6	38,357
#4	1975	1090	1.5 mile	170	510	32	43,189
#5	2030	1200	1 mile	151	205	22	16,305
#6	2225	1150	1 mile	122	495	32	21,898
#7	2053	1260	1 mile	83	515	25	13,230
#8	2110	1635	1 mile	42	1195	30	1,706

It is important to point out that none of the above mechanics are truly new to the field of reservoir engineering. All the principles involved are included in the models and modern compositional reservoir simulators. The so-called dewatering plays, being actively pursued in Oklahoma, seem to have a strong analog to the San Andres depressuing play. But what is new is industry's ability to isolate this recovery process from mobile oil production and witness the principles at work within the ROZs. The advancing drilling and completion technologies have made oil recovery commercial in certain conditions like those of the Type 3 ROZs of the San Andres formation in the Permian Basin. Undoubtedly, other ROZs in other formations and basins will also be exploited in the future.

The mile-long lateral type well for the DUROZ play is illustrated in Figures 8.4 and 8.5. Note that the history of the play is just over a year so the long term behavior is still not known

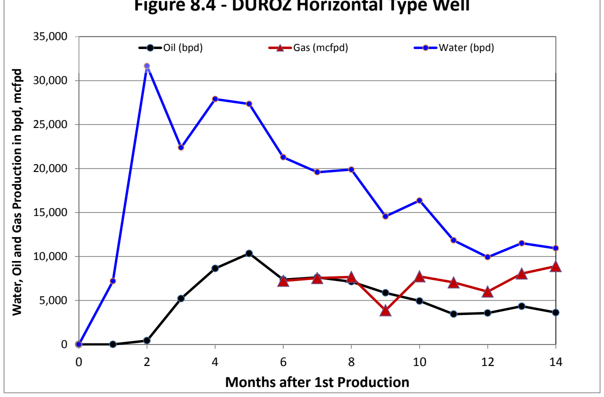


Figure 8.4 - DUROZ Horizontal Type Well

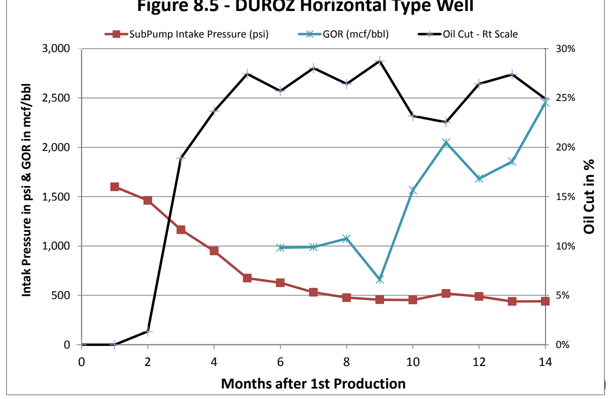


Figure 8.5 - DUROZ Horizontal Type Well

with certainty but projections would suggest per well recoveries will reach 250,000 to 350,000 barrels per well.

One of the required conditions for DUROZ success is that the gas in solution discussed above be sufficiently robust and that a strong water drive not be present that precludes the necessary pressure reductions from the water extraction needed to release the oil.

The development strategies identified herein for the depressuring ROZ play are as follows:

1. Go to a ROZ Fairway Location, seek and secure a water disposal option (all ROZ depressuirng wells to date produce water cuts in the range of 75-85%)
2. Target the horizontal landing depth in the good gas/oil ratio ROZ interval (e.g., upper, highly fluorescing oil intervals)
3. Expose a large section (e.g., long lateral)
4. Stimulate the zone
5. Pump very large volumes of the water until reservoir pressures falls below ‘bubble point’
6. Be patient while producing large volumes of water
7. Watch oil cuts rise
8. Build the surface and well infrastructure and unitize the desire acreage readying for CO_2 injection in the subsequent stage EOR process

The work performed by the authors to date would suggest that the peculiarities of the San Andres ROZ in the Permian Basin are not completely unique. So, if one were anxious to seek out another ROZ fairway in another Basin to evaluate the opportunity for ROZ depressuring, we can outline some reservoir conditions that would be supplemental to the “ROZ cookbook” as presented in Chapter 5. These would involve assuring the oil to be gassy so that the expansion of the residual oil upon depressuring would occur. The viscosity of the oil will also play a role with the heavier oils and their higher interfacial tensions providing resistance to removal of the crude oil from the rock and movement through the pore throats.

One of the challenges of producing residual oil has always been the large capital expenditures associated with reconfiguring a water flood for EOR. The time between the capital expenditures and tertiary oil production can challenge the time value of the project and cause it to lose stature in a portforio of investments. What the DUROZ play does to help is allow a quick return on investment while accomplishing some of the infrastructure buildout (e.g., wells, surface facilities, pooling of leases) for a later stage EOR project. But since the DUROZ play is new, it may be years before the follow-on EOR concept can be tested.

Chapter 9 - Investigations of Residual Oil Zones Outside of the Permian Basin

L. Stephen Melzer; Overall Chapter - Lead Author

Enhanced Oil Recovery Institute, Wyoming; Authors for the Big Horn Basin Subchapter

Melzer Consulting; Lead Author for Williston Basin Subchapter

9.1 INTRODUCTION

The initial ROZ studies, i.e., Permian Basin San Andres formation ROZ investigations, evolved as an attempt to explain the very thick zones of continuous residual oil saturations observed present there. Historically, the thick intervals of residual oil, sometimes observed to be 300’ or more, had been rather cavalierly explained away as transition zones (TZs) where capillary forces and surface tension caused the smearing of oil saturations to zero beneath a main pay zone (MPZ). As time passed, the problems of the TZ model became more numerous and obvious. First, those TZ processes were (and still are) often appropriate when thicknesses are tens of feet but challenge the physics and common sense when hundreds of feet thick. Secondly, ROZs were seemingly ubiquitous in the San Andres and even occurring where no overlying MPZ was present. How could the oil saturations transition below MPZ values when no overlying MPZ existed? Thirdly, many of the well documented oil fields illustrated tilted oil/water contacts (OWCs) suggesting that hydrodynamic forces were present at and below the OWCs (Hubbert, Ref 9.1). Clearly, a new model was needed but not much attention was given the dilemma since all commercial interests were focused on mobile oil and MPZs.

In the 2005-2006 timeframe, interest in ROZs changed as the Permian Basin region of West Texas began showing that the resources of residual oil below the OWC could be commercially exploited (Melzer {2006, Ref 9.2}) via EOR and/or depressuring (see Chapter 8). In retrospect, the deepening of wells below the MPZs in the Wasson and Seminole fields was the dawn of the new ROZ age. This new model of ROZs with the residual oil left behind by “mother nature’s waterfloods” had witnessed a commercial outlet and the new paradigm and understandings added a new dimension to oil recovery.

From a hydrological perspective, work had been done in many oil basins around the globe looking at subsurface water flow and water flow pathways. It is fair to say that the work was most often quite independent from commercial oil and gas related research although data from the oil and gas industry was often essential for the hydrodynamic studies. However, some of this past work looked at subsurface water flow paths with an oil industry perspective but, emphasized finding the new home of displaced oil from a paleo entrapment. Some modern entrapments defied the standard static stratigraphic and structural trap geometries and needed a hydrodynamic expression. This report and investigation took advantage of the previous regional hydro studies but was different in that it now looked at where the oil was displaced from and not where it was secondarily entrapped (Refs 9.3, 9.4). Mapping of the displacing fairways and time variable magnitudes of the displacing gradients were still important but now with an emphasis on the paleo entrapments from which the oil was moved.

As stated above, when oil companies in the Permian Basin began to deepen their fields into the intervals below the OWCs, the commercial interests reinforced the aforementioned concept of TZs to be reexamined. The two concepts of ROZ fairways and greenfield ROZs reported herein were developed as a result of the new investigations. In a sense, no systematic methodology had been developed to identify, model and characterize ROZs since the commercial value of ROZs had not been established to warrant a detailed examination.

This report has emphasized the Permian Basin hydrodynamics and ROZs but is the Permian Basin unique? To begin to address that question, two other basins were selected to examine and extend the concepts of laterally swept, type 3 ROZs.

9.2 ROZ POTENTIAL OF TENSLEEP SANDSTONE IN THE BIGHORN BASIN, WYOMING

Authors: Peigui Yin, Nick Jones, Matthew Johnson, Enhanced Oil Recovery Institute, University of Wyoming

9.2.1 INTRODUCTION

The first basin outside of the Permian Basin chosen to study was the Big Horn Basin in northwestern Wyoming. As outlined in Chapter 5, basin reconstruction through geologic time was critical A thorough paper discussing the ancestral Big Horn Basin (Ref 9.4) attempted to familiarize readers with the very large Permian Age Basin that covered most of western Wyoming and part of NW Colorado and Utah (Fig. 9.2.1). The ancestral basin had clearly been modified by the Laramide Orogeny some 200 million years after the Permian creating new, repositioned oil traps all over western Wyoming, outcropping of formations that were previously many thousands of feet deep, moving oil and water around in the subsurface, and causing major spills of oil to the surface.

The oil of the present-day Big Horn Basin is sourced from the Phosphoria Formation of Permian age. It is named for the phosphorous content in the rocks and the characteristic compositional signature of oil that it contains. It overlies the Tensleep formation which is has produced over 35% of the State of Wyoming's oil through the last century.

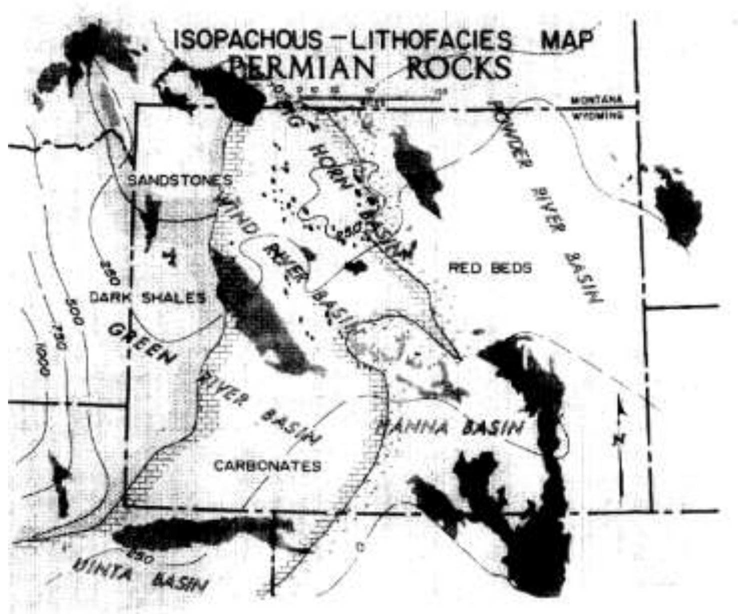


Fig. 9.2.1 – Map of the Ancestral Big Horn Basin Illustrating the Permian Lithofacies (Ref 9.4)

New interpretations of previously acquired core measurement and well log analysis in the Big Horn Basin of Wyoming are showing that the Tensleep reservoirs in the basin contain massive ROZs with oil saturation as high as 70%. The oil in place (OIP) of ROZs in the Tensleep Sandstone of Bighorn Basin is much more than the remaining oil within the main pay zone (MPZ) after artificial water flooding. ROZ formation mechanisms are analyzed through basin tectonic movement, hydrocarbon migration and accumulation, oil composition, and reservoir properties. As mentioned above, oil in the Tensleep reservoirs of the Bighorn Basin was originally sourced from the shale facies of Phosphoria Formation in the west and migrated into the Tensleep Sandstone in stratigraphic and broad structural traps through unconformities. During the Laramide movement, the Tensleep oil re-migrated into steep Tensleep structural traps on the basin flanks and other Paleozoic formations. Expulsion of the Tensleep Sandstone on the surrounding mountain areas due to erosion caused the meteoric water to flush downward, changing oil distribution in the Tensleep reservoirs. Re-distribution of oil during the recent period left massive oil in ROZ below the main pay zone and areas surrounding the existing reservoirs, as well as in the non-developed oil-bearing structures. Some of the oil in Tensleep ROZ is mobile based on completion tests and its composition is similar to that of MPZ oil. After decades of man's water flooding, the residual oil saturation in the MPZ of Tensleep reservoirs has been reduced to that in the ROZ or even lower, and the average water cut in currently produced oil from MPZ is over 98%. Development history of ROZ in the Permian Basin reservoirs has demonstrated that CO_2-

EOR is a promising technique for recovering oil from ROZ in the mature Tensleep reservoirs and un-developed oil-bearing structures.

9.2.2 BIG HORN BASIN FINDINGS

Based on the ROZ concept for the Permian Basin San Andres formation as presented in this report and in Refs 9.2 and 9.5, the Enhanced Oil Recovery Institute analyzed the Bighorn Basin Tensleep Sandstone to identify and evaluate ROZ potential. There are some similarities between Tensleep and San Andres, such as multiple oil migration caused by several episodes of tectonic movement and meteoric water flush from the surrounding mountain outcrops. However, there are also some differences between the Bighorn Basin Tensleep sandstones and the Permian Basin San Andres carbonates. Beside the lithologic difference, oil is heavy in the Tensleep reservoirs, ranging from 13.3 to 44.7° API, compared to the San Andres oil ranging from 53° to 26° API (Ref 9.6). Therefore, a set of different study methodologies must be created with reference to the Permian Basin ROZ study.

Development of the Bighorn Basin began as early as 1884, and 90% of the oil came from Paleozoic reservoirs. Tensleep Sandstone is the dominant Paleozoic reservoir in the Bighorn Basin. The first Tensleep oil reservoir was discovered in 1922 (Ref 9.6), and there are 58 Tensleep reservoirs that have been produced oil in the Bighorn Basin. Water flooding has been conducted in the Bighorn Tensleep reservoirs for several decades. During the long period of exploration and production in the Bighorn Basin Tensleep Sandstone, different development standards were used to determine the development intervals based on not only the oil saturation and water cut, but also with consideration of economic climate. As a consequence, a huge volume of Tensleep oil-bearing sandstones, some sandstone intervals with oil saturation up to 70 percent, were not developed during the primary and secondary production.

Zapp (1956, Ref 9.7) constructed a structural contour map and identified 12 Tensleep reservoirs with tilted oil-water-contact (OWC). The inclination magnitude ranges from 50 to 800 feet per mile. The OWC inclination directions are generally toward the basin center, indicating meteoric water flushes into Tensleep sandstones from outcrops in the surrounding mountains. The Tectonic Map of the Bighorn Basin compiled by Ver Ploeg (1985, Ref 9.8) contains tectonic units (anticlines and synclines) and represented exploration wells with oil fields outlined. It is very interesting to note that so many exploration wells drilled on many structures without existing reservoirs are not productive after completion. Even multiple wells were drilled on a single structure. It was tentatively interpreted by the authors that although hydrocarbon shows were found in these wells, but they were not valuable for development under the economic conditions at that time. With new technologies developed and high oil price, oil resources those are not worthy to develop before may be valuable today.

Personal communications with geologists and engineers working in the Tensleep reservoirs strengthen the confidence to work on residual oil zone in the Bighorn Basin. Chris Mullen (Ref 9.9) mentioned that perforation intervals in most Tensleep reservoirs depended on the economic cut offs, such as water cut, even oil saturation was still high in deeper intervals. Perforation too deep will cause quick water coning. This perforation option is potential to leave some oil-bearing intervals without development. Eugene Wadleigh (Ref 9.10) stated that a lot of oil-bearing zones in the Bighorn Basin Tensleep Sandstone perceived by geologists and engineers had not been successfully developed for the primary production.

9.2.3 GEOLOGICAL SETTING

Bighorn Basin is a rich petroliferous basin, located in the northwestern Wyoming State. This unsymmetrical basin is surrounded by Bighorn Mountain in the east, Owl Creek Mountain in the south, Absaroka Range in the west, and Beartooth Mountain and Pryor Mountain in the north (Fig. 9.2.2). The Bighorn Basin is elliptical, with an axis trending northwest-southeast. The elevation of basin floor averages 5000 feet and several surrounding mountain ranges are 10,000-12,000 feet above sea level (Ref 9.11). The precipitation is low in the Bighorn Basin, about 6 inches per year (in/yr), but more than 20 in/yr in the surrounding mountains.

Fig. 9.2.2. Bighorn Basin, adopted from USGS National Assessment of undiscovered oil and gas resources of the Bighorn Basin province, Wyoming and Montana, 2008

Most of the groundwater recharge is from infiltration of snowmelt at outcrops in the mountain areas (Ref 9.11).

The Paleozoic sequence in the Bighorn Basin includes, in ascending order, Cambrian Flathead Sandstone, Gros Ventre Formation, and Gallatin Formation, Ordovician Bighorn Dolomite, Devenian Jefferson Dolomite, Mississippian Madison Formation, Pennsylvanian Darwin Formation, Amsden Formation, and Tensleep Sandstone, and Permian Phosphoria Formation (Table 9.2.1). A significant erosion event occurred on the top of Tensleep Sandstone. Beside the Tensleep Sandstone, important Paleozoic oil-productive horizons in the Bighorn Basin also include Permian Phosphoria and Mississippian Madison carbonates. Other formations, such as Flathead Sandstone, Bighorn Dolomite, and Jefferson carbonate, contribute only a few percent of hydrocarbons to the Bighorn oil production.

Table 9.2.1. Paleozoic stratigraphic sequences in Bighorn Basin, modified from Stone, 1967

Period	Formation	Lithology
Permian	Phosphoria	Dolomite, limestone, shale
Pennsylvanian	Tensleep	Sandstone, dolomite
	Amsden	Sandstone, red shale, limestone, dolomite
	Darwin	Sandstone
Mississippian	Madison	Dolomite, limestone
Devonian	Jefferson	Dolomite
Ordovician	Bighorn Formation	Dolomite
Cambrian	Gallatin	Sandstone, limestone, shale
	Dunoir	Limestone
	Gros Ventre	Sandy limestone, shale, sandstone
	Flathead	Sandstone

The Tensleep Sandstone is composed of eolian sandstones alternated with marginal marine dolomite. The Tensleep sandstones are white, weathering dun, hard-friable, massive to cross-bedded, moderately to well-sorted, fine- to very fine-grained, whereas the dolomite intervals varies, from pure dolomite to sandy dolomite with different detrital sand grain content. The upper portion of Tensleep is sandstone dominant, whereas the lower portion of Tensleep contains more dolomite layers. The tight dolomite intervals serve as berries or baffles in the Tensleep reservoirs, separating the sandstones into several poorly connected zones or separate compartments. However, heavy fracturing in some structural reservoirs is potential to provide fluid conduits between sandstone intervals. Due to intensive cementation by dolomite and anhydrite in some sandstones, the Tensleep sandstone intervals also become heterogeneous with respect of fluid communication. In addition, large-scale cross beddings within the Tensleep sandstones further cause reservoir anisotropy and heterogeneity. The sandstone heterogeneity and anisotropy play an important role in oil migration, accumulation, and recovery efficiency.

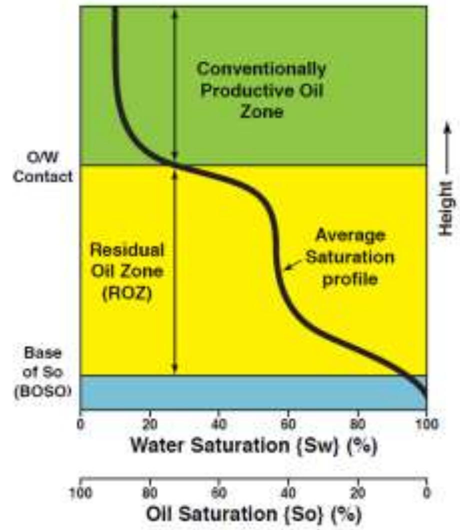
Prior to the Laramide Orogeny, the Tensleep Sandstone and Phosphoria Formation were located on the eastern Cordilleran Cratonic Shelf with broad structures related to the topography on the surface of underlying Madison carbonate sequence (Refs 9.12, 9.13). The initial dip of the Pennsylvanian and Permian rocks is toward the west (Ref 9.14). After the intensive Laramide tectonic movement, all the Paleozoic sequences are folded and faulted. As a result, most of the current Tensleep reservoirs are sharp anticlinal traps, with a steep slope on one side and a relatively gentle slope on another side. The majority of the anticlinal fields with high oil column and effective vertical closure are characterized by multi-oil zones within some or all the Paleozoic sequences. These oil zones in different Paleozoic formations often display a common OWC, indicating heavy fractures and faults are developed through all the Paleozoic sequences.

The Tensleep Sandstone is outcropped on the surrounding mountain terraces, and all Tensleep oil reservoirs are located on the basin slopes. The hydraulic head over most of the Bighorn Basin is close to the land surface elevation and the formation water is surprisingly fresh (Ref 9.11), indicating strong meteoric water recharges from the surrounding mountains toward the basin center. As a consequence, most of the Tensleep reservoirs are characterized by active water drive. With production, water quickly encroached into the main pay zones.

9.2.4 METHODOLOGIES

Concept and methodologies of the Permian Basin ROZ study provide a useful reference for us (Fig. 9.2.3). Numerous reports, published papers, and conference presentations in the Permian Basin ROZ study and reported herein have formed a baseline for the Big Horn studies. Personal discussions with their researchers have been beneficial for this study. In addition, recovery of oil from the Permian Basin ROZ has encouraged EORI to precede the Tensleep ROZ study, and also provide us some useful information for ROZ development.

Fig. 9.2.3. Definition of MPZ and ROZ, adopted from Melzer, 2013



The project compiled, synthesized, and interpreted information from different resources. Extensive data collection was conducted in the first stage and continues during the study, including core analysis data, core and cutting investigation, petrographical analysis, well test data, and development history for the Tensleep Sandstone from Wyoming Oil and Gas Conservation Commission, PI/Dwight, Wyoming Geological Survey, USGS Core Research Center, and published literatures. Tensleep cores from seven wells and cutting from three wells are investigated to check hydrocarbon shows, and 355 thin sections from 47 wells spreading over the Bighorn Basin have been examined to investigate mineral composition, diagenetic changes, porosity distribution in both MPZ and ROZ, and hydrocarbon stain coating sand grains.

A small region (Sage Creek-Deaver-Cowley-Homestead region) with plentiful data is selected for the detailed study. In this region, all the usable well logs were digitized; oil saturation and porosity calculated from log analysis are calibrated with core-measured values; and a geological model is constructed to estimate oil resource in the ROZ. Detailed investigation in this region also created a set of methodologies for the ROZ study in other regions of Tensleep Sandstone, as well as in other formations of Wyoming State.

In order to understand ROZ formation in the Bighorn Basin Tensleep and predict the favor areas for ROZ development, oil generation, migration, and accumulation processes were studied through reviewing literatures and analysis of tectonic movement. Investigation of Tensleep outcrop distribution and annual precipitation in the Bighorn Basin and surrounding mountains provide information on meteoric water recharge to the Tensleep sandstones, and hydrological information in the Bighorn Basin and surrounding mountains is helpful to predict the hydrodynamic activities. Mineral changes in the Tensleep Sandstone provide information on diagenetic modifications, and oil properties in both MPZ and ROZ are used to predict the possible oil degradation in ROZ.

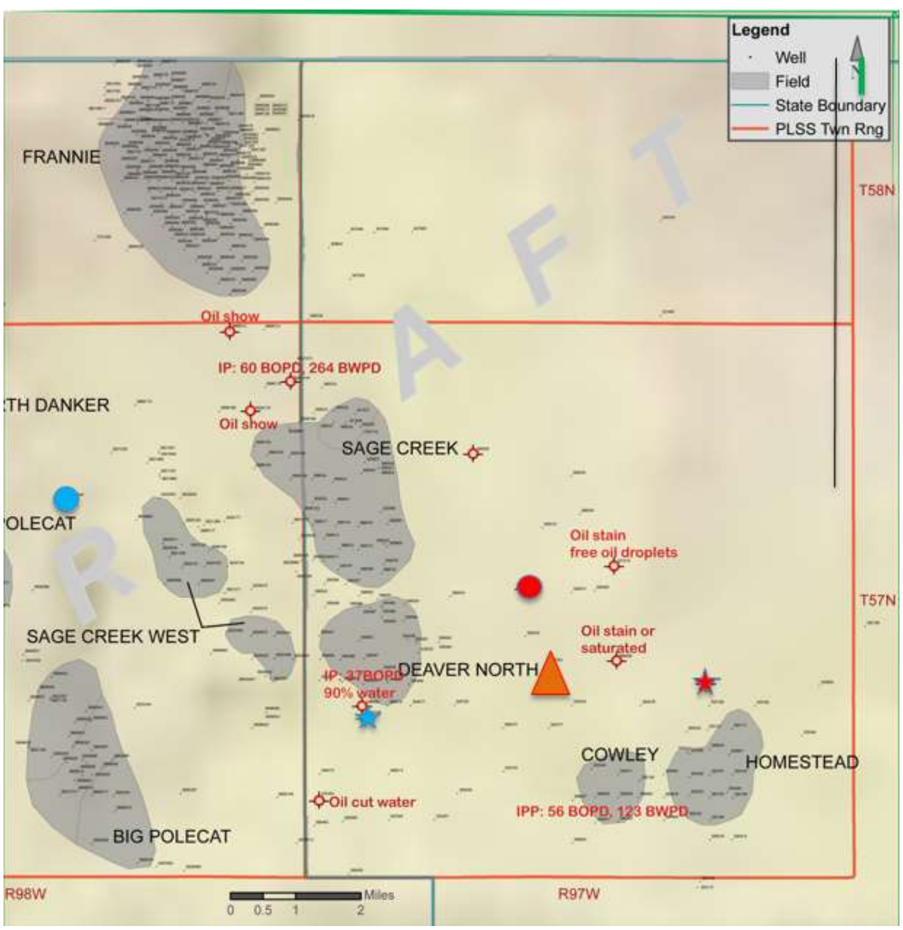
9.2.5 RESIDUAL OIL ZONE (ROZ) in TENSLEEP SANDSTONE, BIGHORN BASIN.

9.2.5.1 Distribution

Residual oil zones (ROZs) in the Tensleep Sandstone are widely distributed over the entire Bighorn Basin slope. ROZs are recognized below the main pay zones in the existing Tensleep reservoirs, around the existing reservoirs, and in the undeveloped oil-bearing structures.

In the Sage Creek-West Sage Creek-North Deaver-Cowley-Homestead region, hydrocarbon shows are widely observed (Fig. 9.2.4).

Fig. 9.2.4 - Hydrocarbon shows in wells around the existing Tensleep reservoirs in the Sage Creek-West Sage Creek-North Deaver-Cowley-Homestead region



Available data indicates that most of the wells located between the existing Tensleep reservoirs in this region displayed hydrocarbons shows during well drilling and/or completion, either recovery some oil with high water cut or oil stains on cores or cuttings. Oil saturation on the four representative cores presented in Fig. 9.2.5 is up to 60 to 80% (Figs 9.2.5, 9.2.6), and all these wells are located outside the existing Tensleep reservoirs, and not developed during the primary and secondary recovery (see Fig. 9.2.4). In addition, the wells with hydrocarbon shows are widely distributed in this region, indicating that the Tensleep sandstones in the entire region were sometimes saturated by oil before flushing by meteoric water. With increasing hydrodynamic activity, the current oil accumulations in this region are result from re-migration of the previous oil accumulations into hydrological favorable positions to generate the current Tensleep reservoirs, left a huge amount of residual oil in the areas where the previous oil accumulated.

Fig. 9.2.5 - Four representative cores with high oil saturation between the existing Tensleep reservoirs. Well locations are marked in Fig. 9.2.4

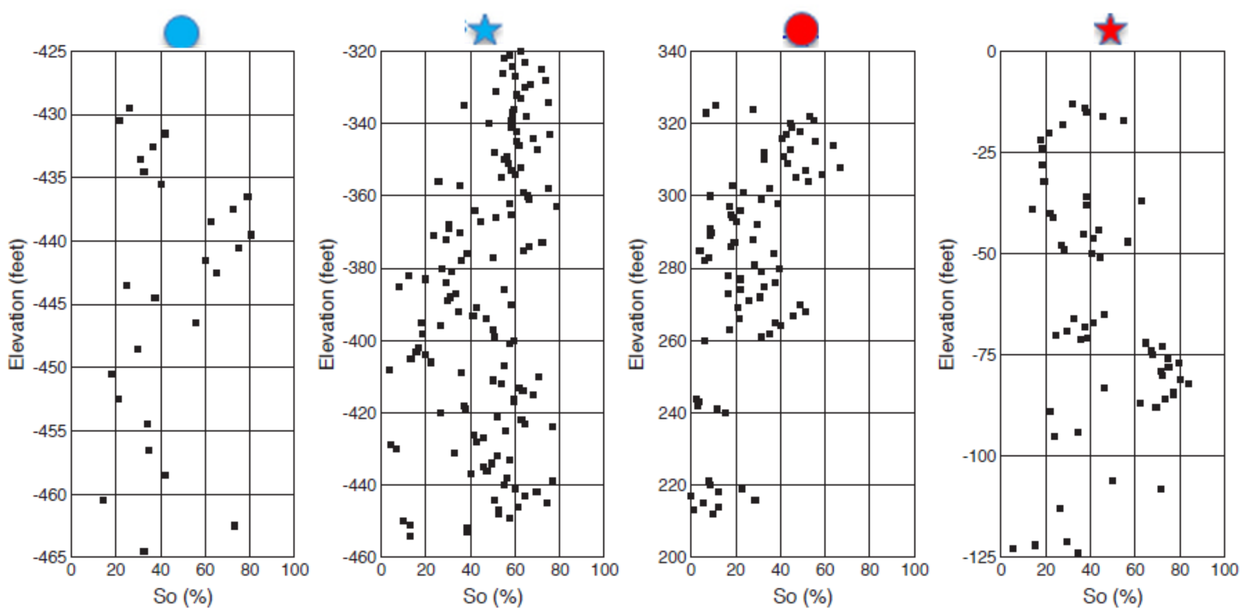


Fig. 9.2.6 - Core from a non-productive well with dense oil stain and oil saturation up to 76%

MPZs in the reservoirs of this region are very thin and concentrated in the upper portion of Tensleep Sandstone. In addition, MPZ in all these reservoirs are not located on the structure tops, rather on the slopes. Oil-water contacts in these reservoirs are tilted, dipping toward the water flow directions. ROZs are identified even on top of the structures with MPZ on the slope (Fig. 9.2.7). Most of the Tensleep reservoirs in this region still show 40% oil saturation in MPZ after artificial water flooding. If 40% of oil saturation is taken as the cutoff for remaining oil in ROZs after the natural water flooding, ROZ portion in the oil-bearing Tensleep interval constitutes approximately 90% in Sage Creek, 78% in West Sage Creek, 75% in North Deaver, 95% in Cowley, and 80% in Homestead (Fig. 9.2.8). The lower intervals were not perforated even the oil saturation was still 60 to 80%.

Fig. 9.2.7 - Cross-sections display large ROZ portion with oil-saturation below 80% in the Sage Creek-West Sage Creek-North Deaver-Cowley-Homestead region. Black lines mark the boundaries between MPZ and ROZ. Vertical exaggeration is 2

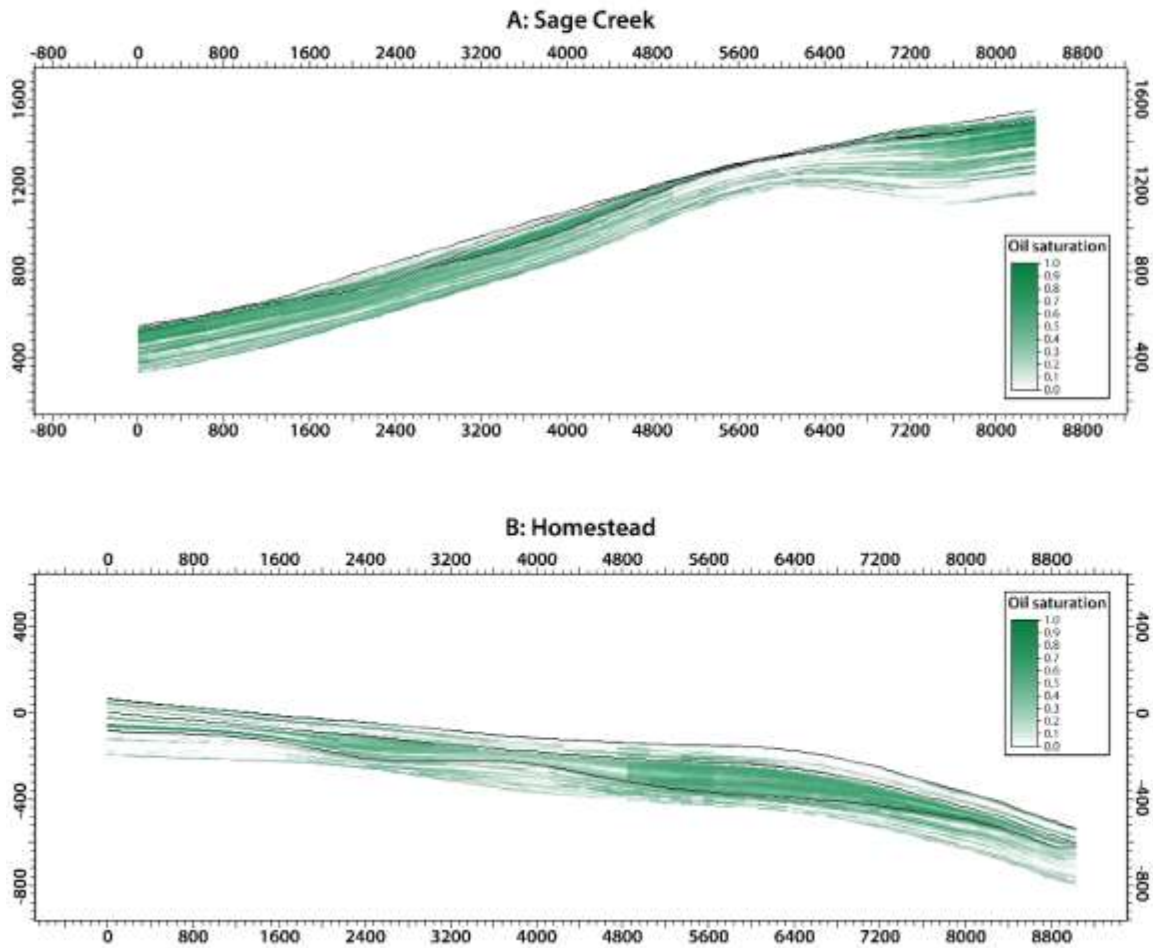
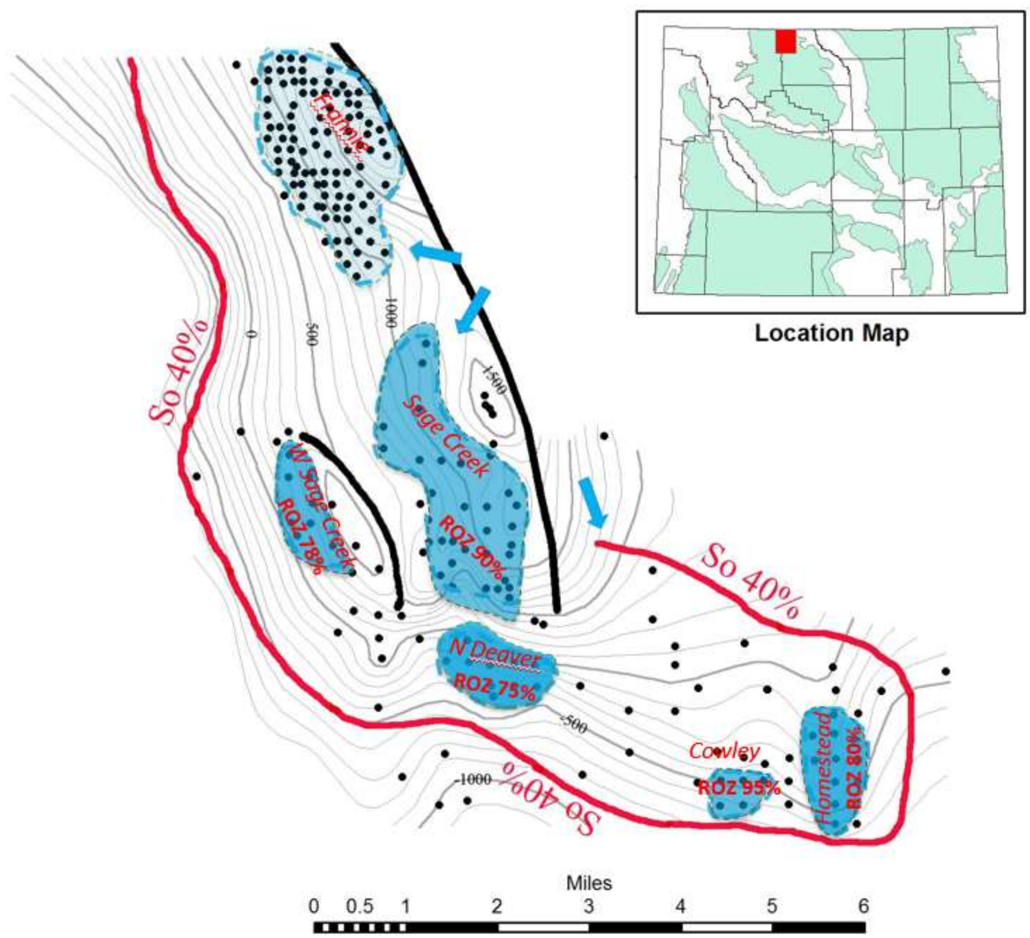
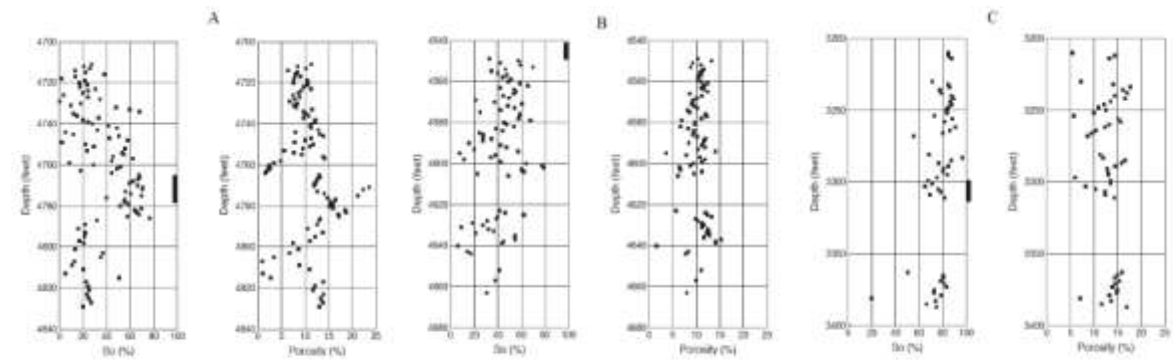


Figure 9.2.8 - ROZ distribution below and around MPZ in the Sage Creek-West Sage Creek-North Deaver-Cowley-Homestead region. Blue dash lines outline the existing Tensleep reservoirs, and red line outlines the area potentially with ROZ.



In many wells over the Bighorn Basin, the deeper sections below OWC in the existing reservoirs still show relatively high oil saturation and even produce some oil in well tests. However, the water cut was too high in the deeper sections, and economics are not favorable for development during the primary and secondary production (Fig. 9.2.9 A, B and C).

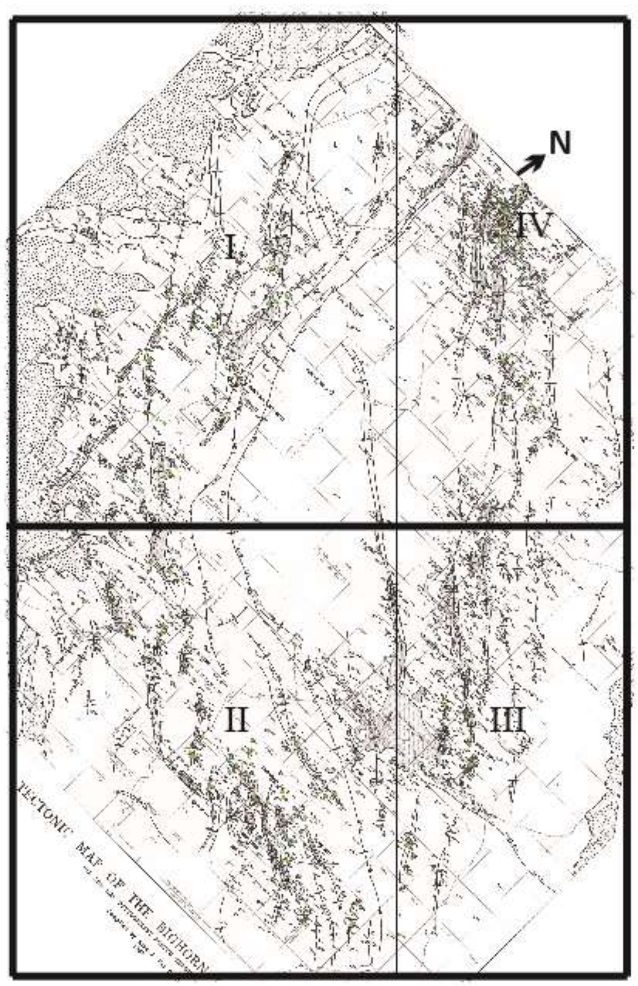
Fig. 9.2.9 - Examples of oil saturation in ROZ below MPZ in existing reservoirs



Data collected from the non-productive wells outside the existing Tensleep reservoirs and on the non-productive structures are marked in the Bighorn Basin, based on the tectonic map created by ver Ploeg (1985, Ref 9.8), including oil shows in drill stem tests and completion tests and oil stain in core or cutting samples (Fig 9.10). Wells with hydrocarbon shows are located over the entire basin slope, but concentrated along the anticlines. Based on the available data, a lot of non-productive wells demonstrate hydrocarbon shows, either with high percentage of oil cut in well test, or with oil saturation from 40 to 70%. In addition, oil drop and stain in cores and cuttings are very common. However, these wells were not produced enough oil to meet the economic requirement during primary and secondary recovery, leaving massive ROZ in these non-productive wells and un-developed structures.

Some representative oil-bearing anticlines, such as Mahoney, Morton, Hose Center, Lucerne, South Nowood, and Gypsum Creek are selected to demonstrate the ROZ distribution. In these anticlines, hydrocarbon shows are very common, either small amounts of oil were tested or oil stains in core and cutting samples (Fig. 9.2.11,12,13,14). Oil saturation is up to 50 to 80% in drilling cores from some representative wells and porosities are much higher above the porosity cutoff for the Tensleep sandstones.

Fig 9.2.10 (Ref Chart below with blowups on next four pages) Hydrocarbon shows in non-productive wells of Tensleep Sandstone, Bighorn Basin. Green dots represent hydrocarbon shows from well tests, and brown cylinders represent oil stains in core or cutting samples. Base map adopted from Ver Ploeg, 1985.



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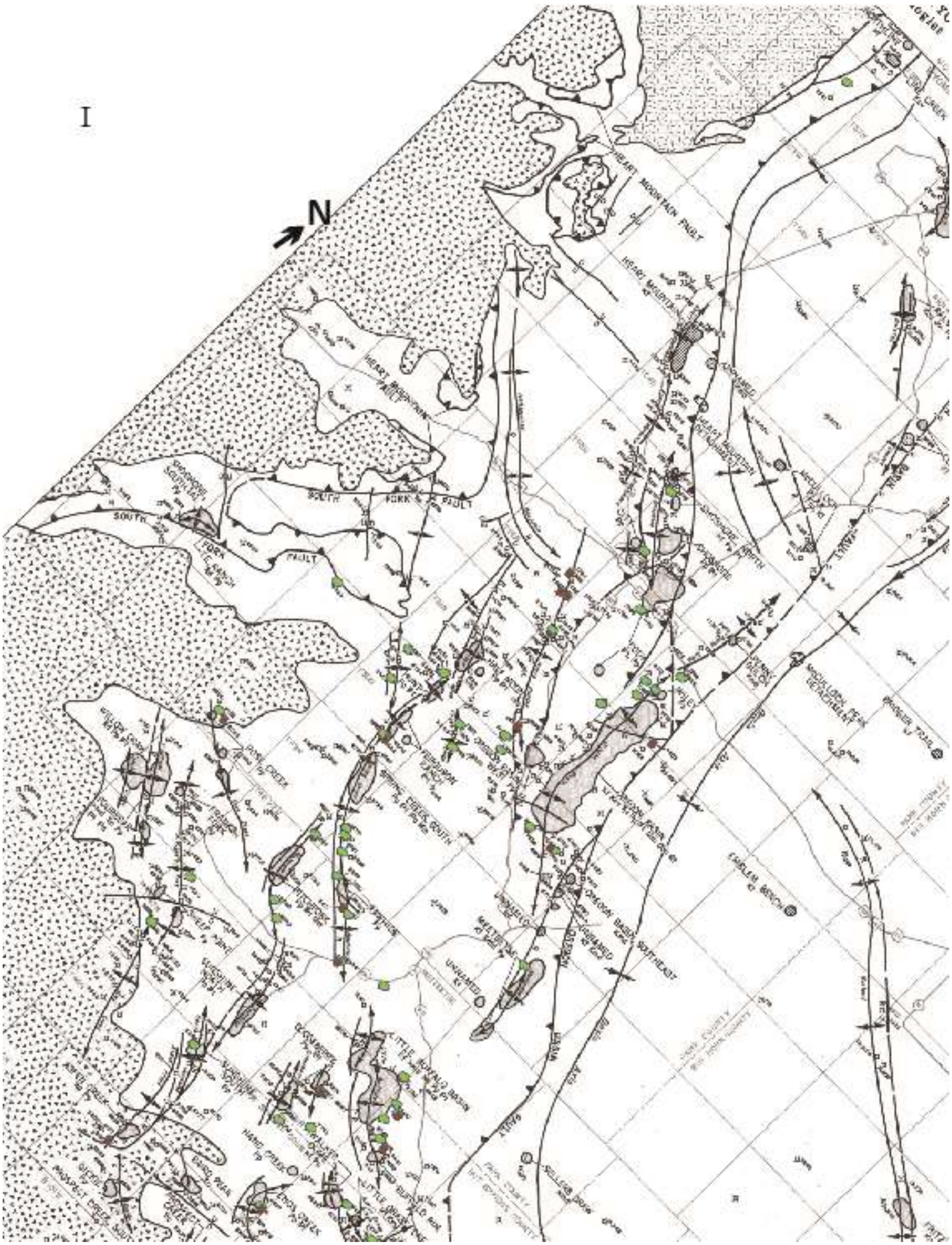

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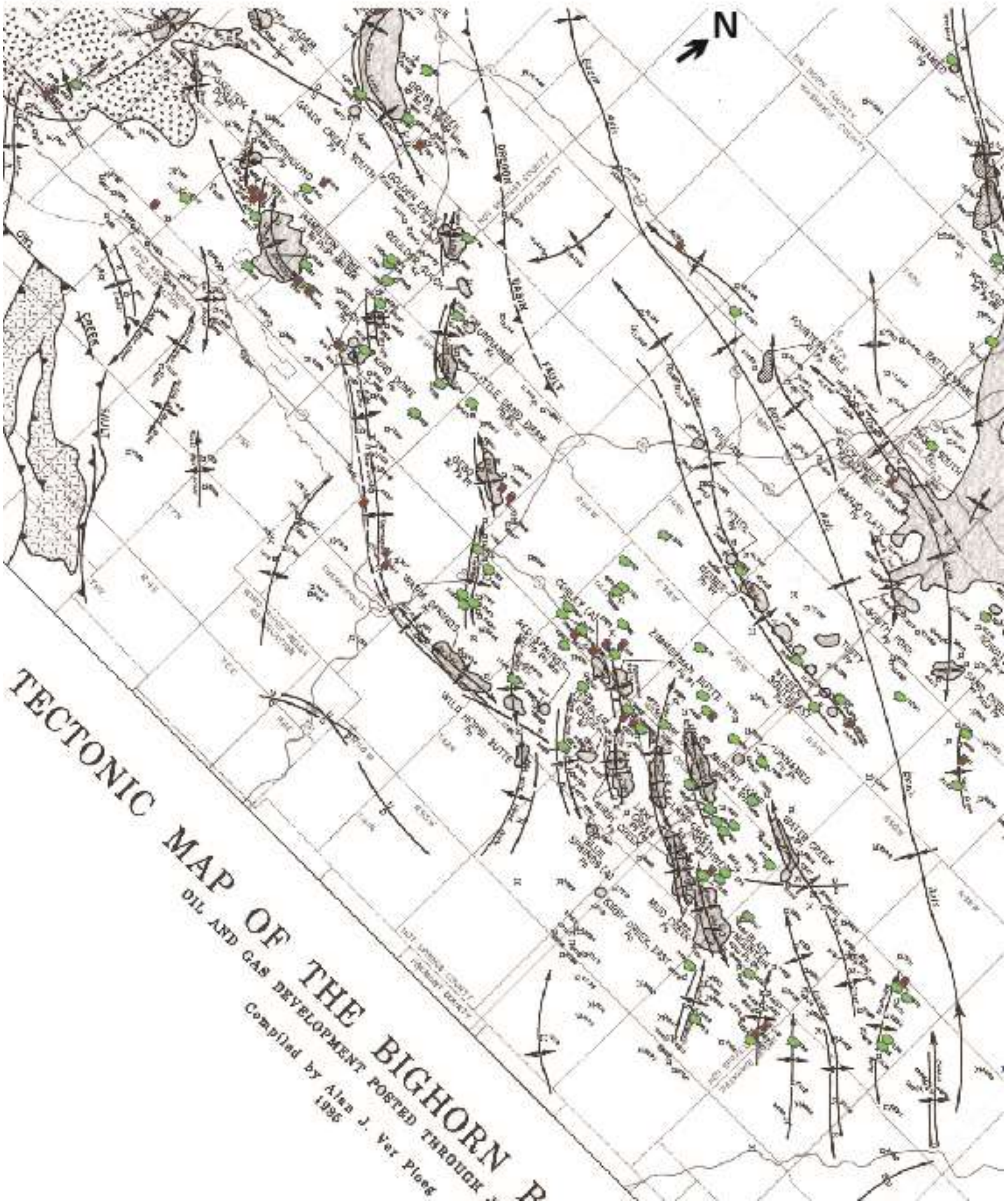
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TECTONIC MAP OF THE BIGHORN B
OIL AND GAS DEVELOPMENT POSTED THROUGH
Compiled by Alan J. Ver Ploeg
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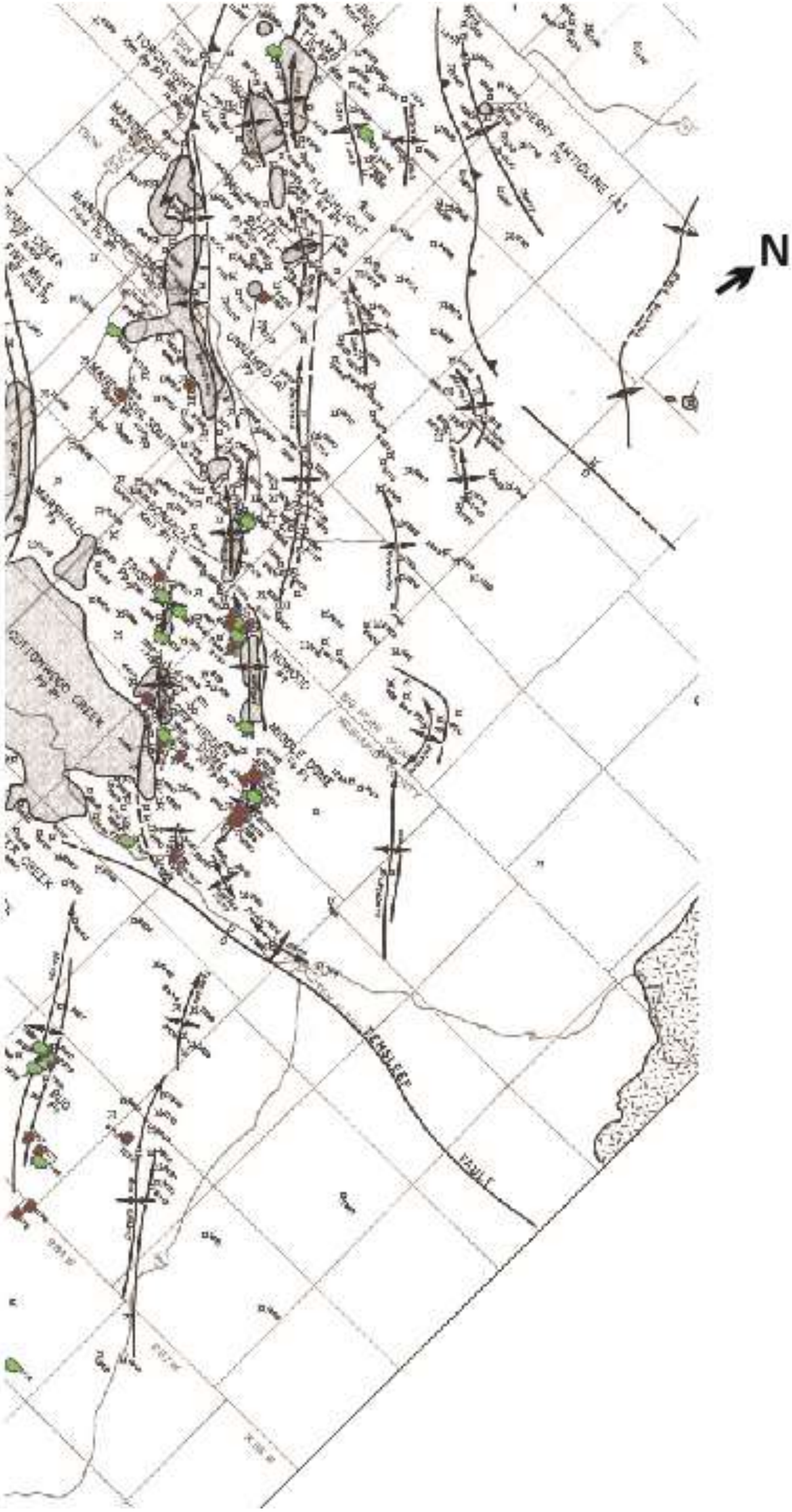

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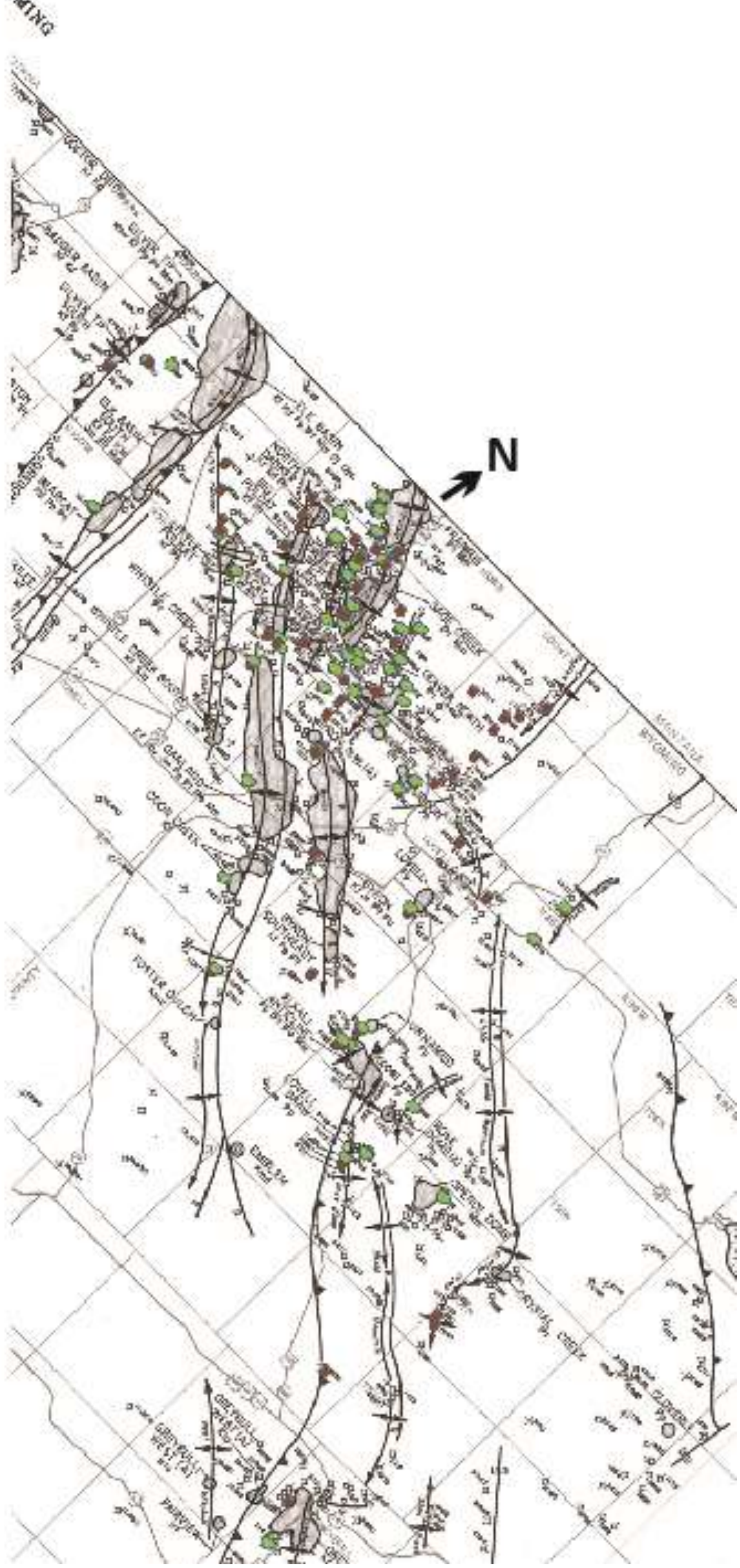


Figure 9. Fig

Fig. 9.2.11 - Non-productive structures close to the Mahogany Anticline (A) with oil saturation up to 50% and porosity above 15% in one well (B) and oil saturation up to 60% and porosity ranging from 10 to 25% in another well (C). The green dot indicates hydrocarbon show in well test, and brown cylinder indicates oil stain in core samples.

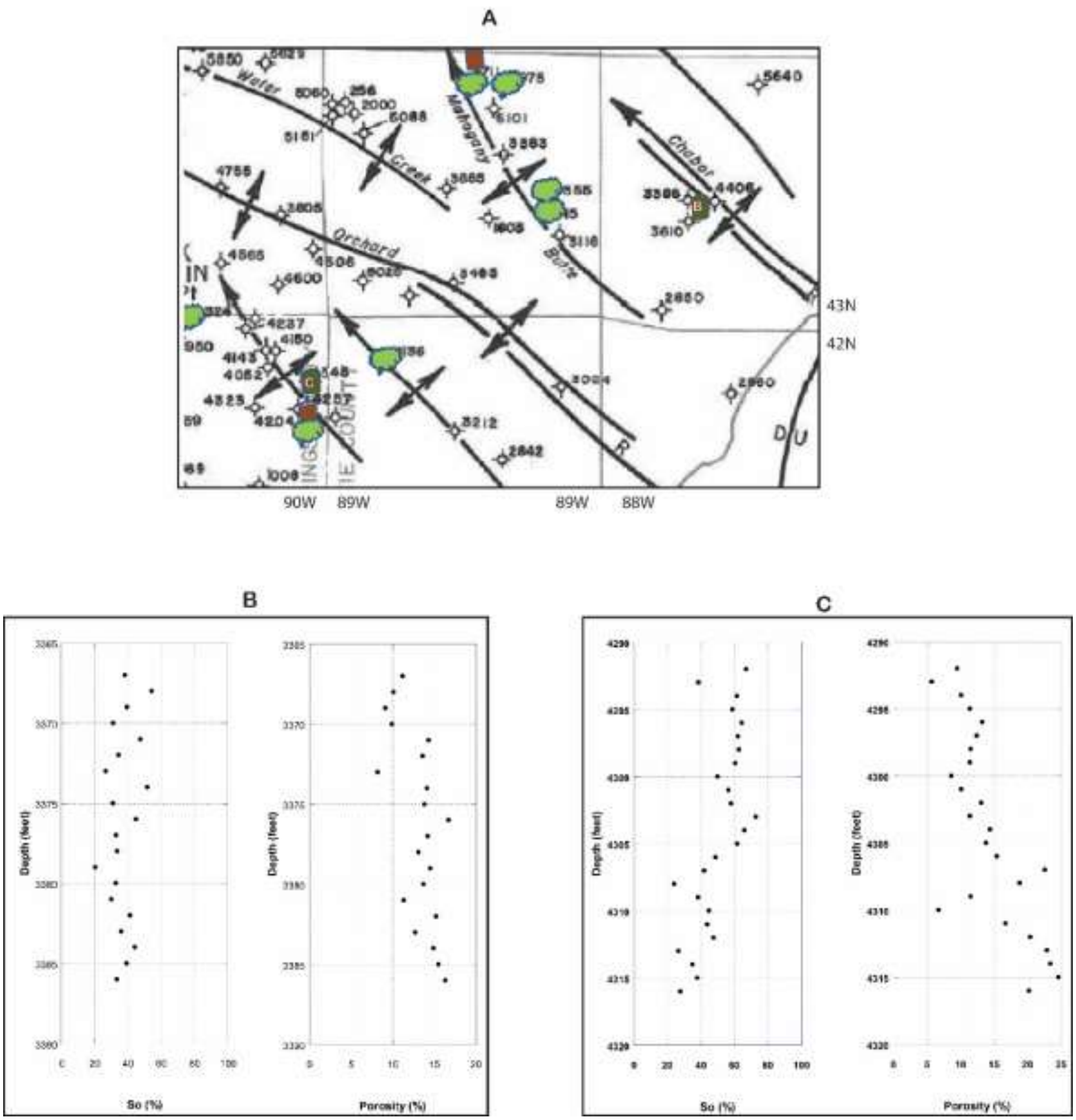


Fig. 9.2.12 - Several non-productive structures around the Morton Anticline (A) with oil saturation up to 60% and porosity above 15% in one well (B)

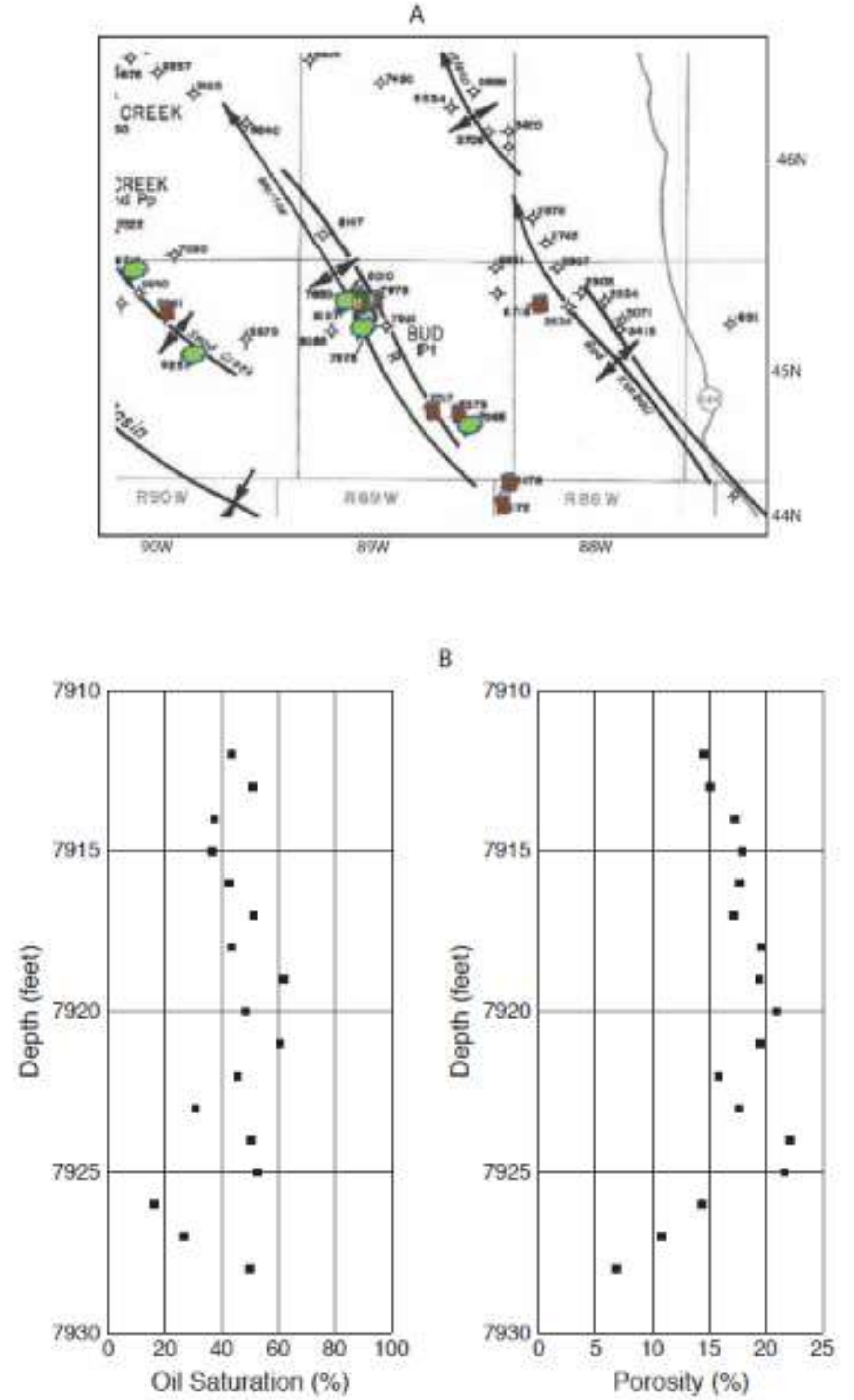
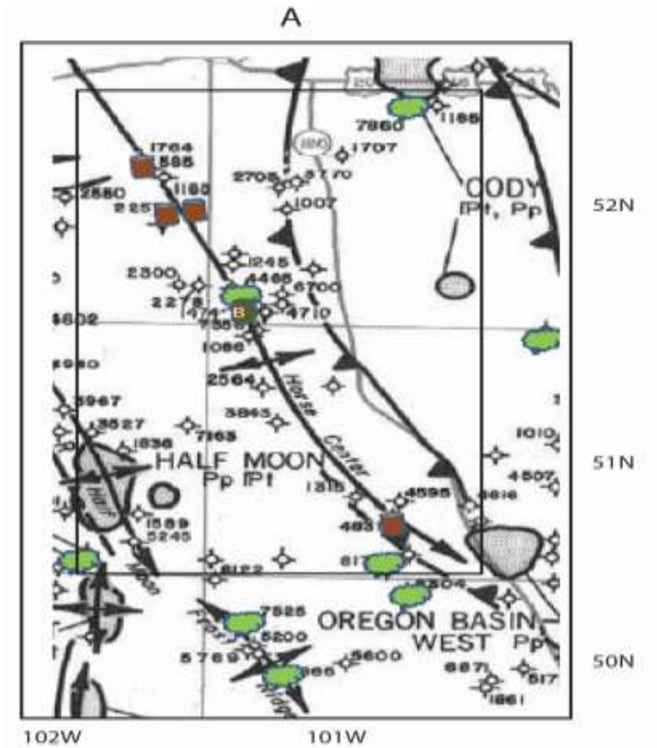


Fig. 9.2.13 - Non-productive structure of Horse Center Anticline (A) with oil saturation up to 80% and most porosities ranging from 10 to 20% in one well (B).



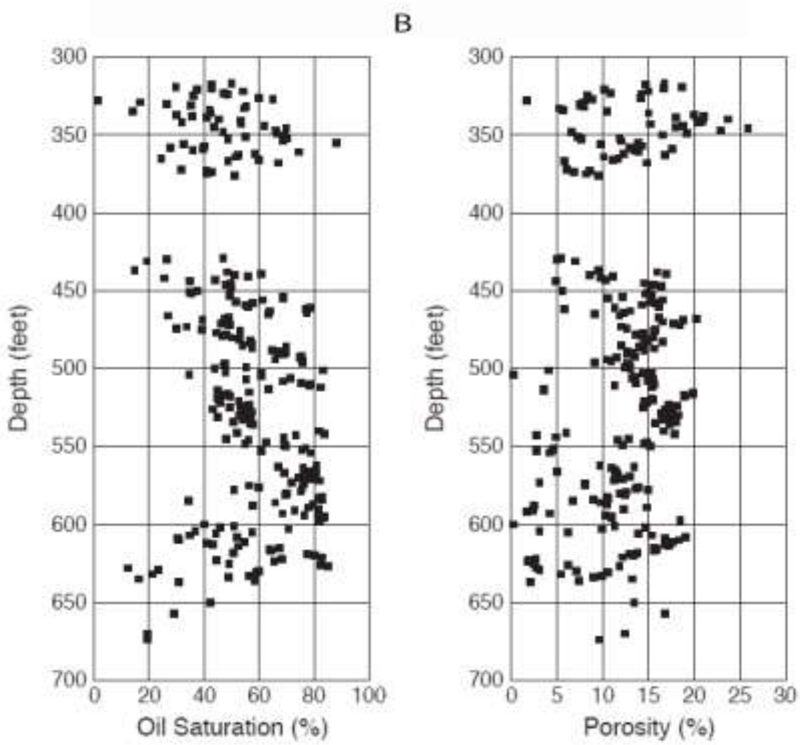
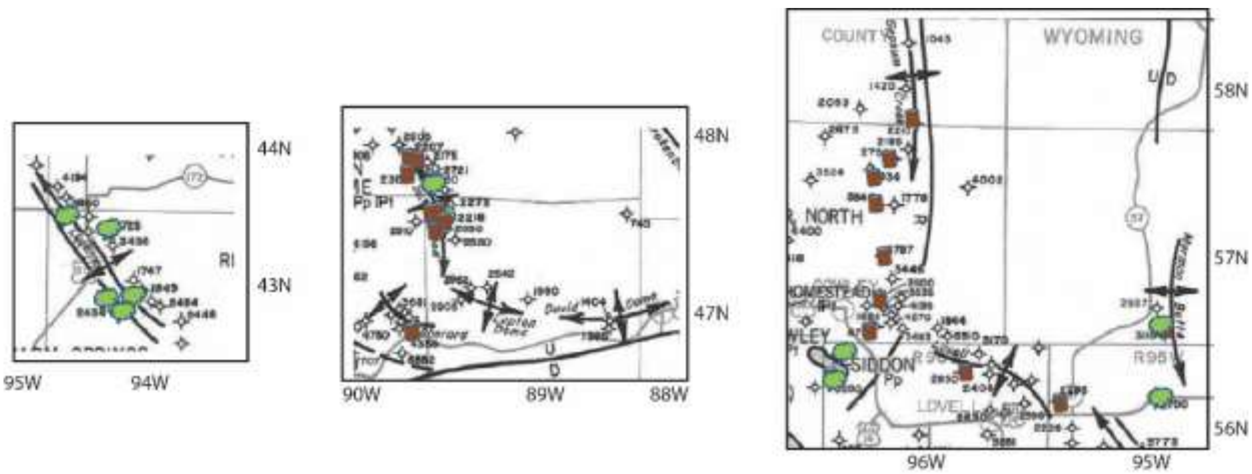


Figure 9.2.14 - Non-productive structures of Lucerne, South Nowood, and Gypsum Creek demonstrate recovery of some oil during completion and hydrocarbon stains in cores.



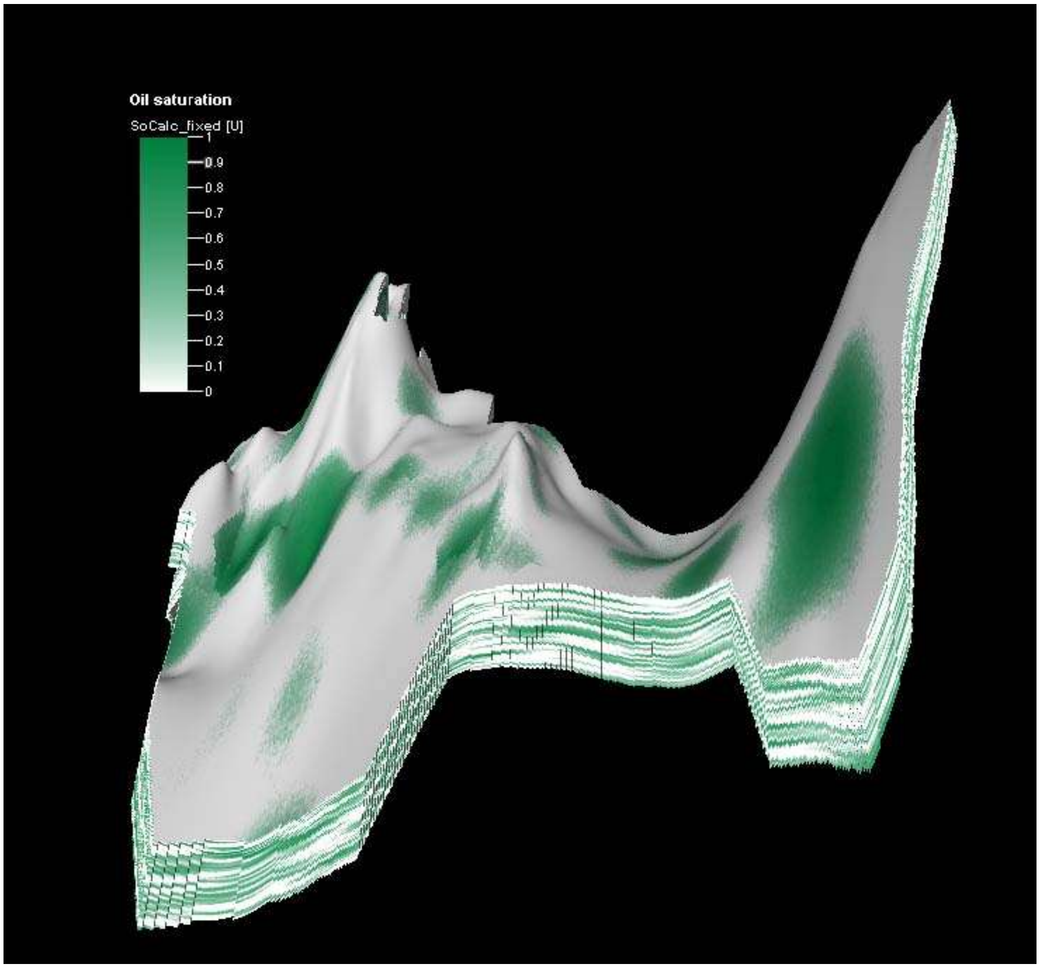
In summary, ROZs are widely distributed over the slope of Bighorn basin, below and around the existing reservoirs and in undeveloped oil-bearing structures. These huge resources are not developed during the primary and conventional secondary production. With current economic environments, some companies have started working on or planned to work on these oil resources.

9.2.6 POTENTIAL RESOURCES

ROZ resources estimation was conducted in the Sage Creek-North Deaver-Cowley-Homestead region (see Fig. 9.2.4). Oil produced in this region is dominantly from Tensleep reservoirs, and only a small portion from the Madison. Works on this estimation include creating a database of core measurements, well log analysis, perforation intervals, well completion history, and oil production in the existing Tensleep reservoirs. Most of wells drilled in this region did not penetrate the entire Tensleep section. A couple of holes in the Sage Creek field reached the bottom of Tensleep, providing the data for the modeling and resource evaluation.

A static geologic model was created using Petrel Software ® to calculate the ROZ resources in this region (Fig. 9.2.15). In this modeling, stratigraphic correlation is established mainly using the GR logs, with reference to other logs and core description. Porosity was estimated based on the sonic, neutron, and density logs, and calibrated by the core

Fig. 9.2.15. 3-D geological model of the Tensleep Sandstone with oil saturation. Vertical exaggeration is 10.



measurements. Water saturation was calculated using resistivity logs with reasonable parameters. In addition, fluid saturations measured from the core samples were taken as a reference to check the calculation validity. ROZ interval in existing reservoirs was defined as the Tensleep section below bottom of penetrations, and a horizon separating the MPZ and ROZ was drown based on the perforation bottom with reasonable extrapolation.

Based on the porosity cutoff for oil-productive sands popularly used in the Bighorn Basin Tensleep, sandstones with 8% and higher porosity were defined as pay zone in this estimation. The calculated oil in place in ROZ within Sage Creek-North Deaver-Cowley-Homestead region averages 34,000 barrels per acre. The oil resource in ROZ is a total of 796 MMBO, whereas the remaining oil in MPZ after water flooding is only 45 MMBO. The huge resources of oil in ROZ have impressive potential for enhanced oil recovery.

9.2.7 OIL QUALITY IN ROZ

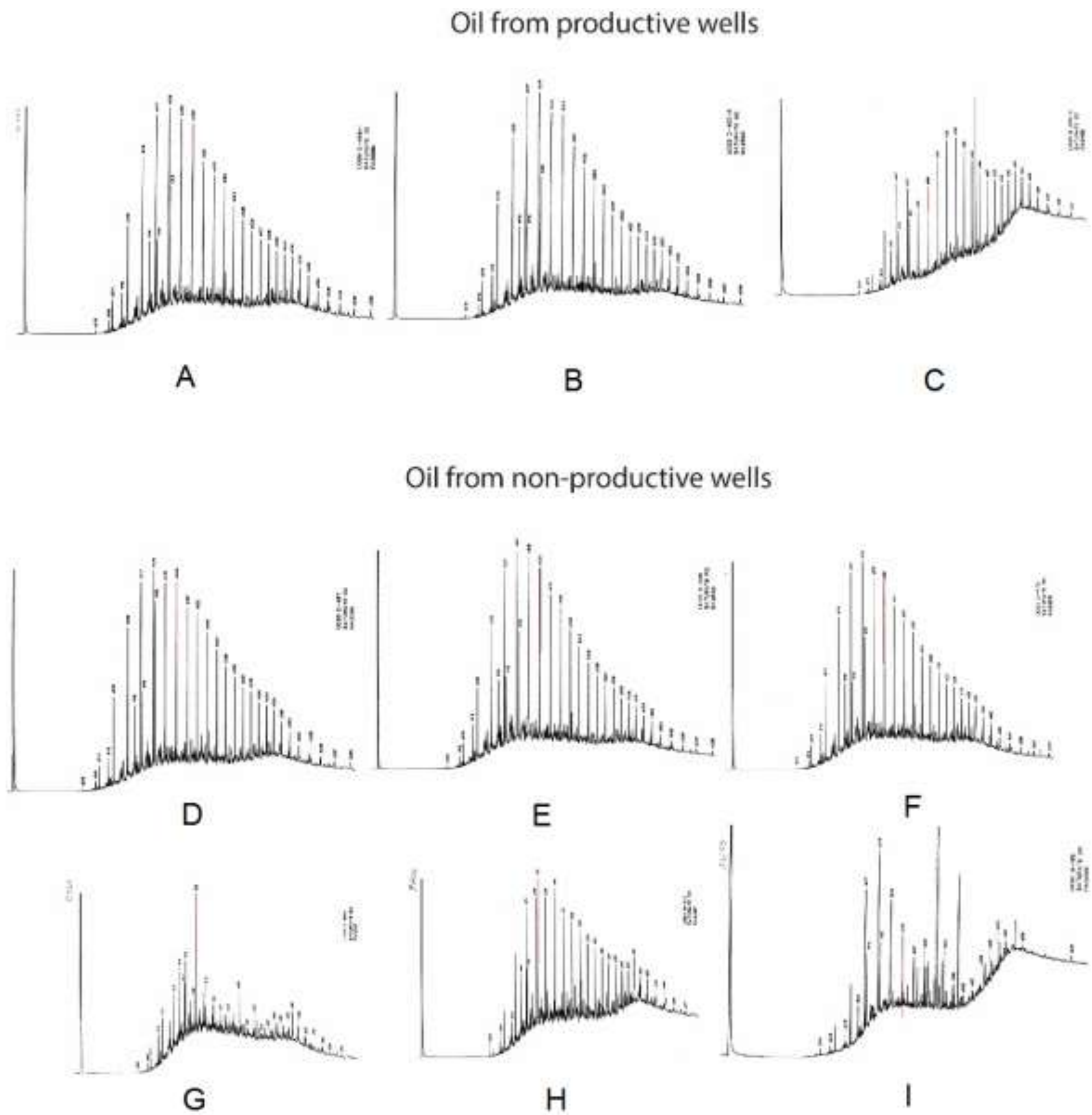
Since oil in the residual oil zones have been washed by meteoric water, oil quality in ROZs is a big concern for recovery of these resources. Data on oil analysis are collected to compare the oils from existing reservoirs with ones from the non-productive wells or structures.

Oil gravity collected from the Tensleep reservoirs ranges from 49° to 14° API, indicating various oil quality in the MPZ. Oil samples collected from some non-productive wells surrounding the existing reservoirs or in some un-developed structures display a little difference of API range as the produced ones. For example, oil gravity in a Tensleep reservoir is 26.4° API, and oil recovered during completion tests from a non-productive well outside this field is 22° API. In another Tensleep reservoir, oil with API gravity of 20° is produced from MPZ, located above 4590 feet, whereas an oil samples from the depth interval between 4740 to 4749 feet is characterized by 19° API gravity. In addition, oil tests in numerous non-productive structures discovered various amounts of mobile oil, indicating that oil in these un-developed ROZs is technically recoverable.

In other examples, oil samples recovered from non-productive wells are much different from the produced oil of nearby existing reservoirs. For example, API gravity of several oil samples from wells located in the one area ranges from 13.3 to 14.7°, whereas oil produced from a Tensleep reservoir close to these wells possesses an API of 22.8°. The same phenomenon is found in one area located on the east basin slope. Oil gravity is 18.2° API and 36.1° API in two adjacent Tensleep reservoirs, compared to the gravity of 14.7°-15.3° and 14.4°-15.3° respectively in oil samples recovered from non-productive wells around this area. Oil in the non-productive wells in this area must have experienced more intensive degradation than the oil in the nearby reservoirs. However, the oils recovered from the un-developed wells are still productive with reference to oil quality in the existing Tensleep reservoirs

Fig. 9.2.16 shows gas chromatographic (GC) patterns of saturated oil from 3 productive wells (Fig. 9.2.16 A, B, and C) and 6 non-productive wells (Fig. 9.2.16 D, E, F, G, H, and I). Some GC patterns from the non-productive wells (Fig. 9.2.16 D, E and F) are close to those from the productive wells, with similar n-paraffin distribution and the ratios of short chain to long chain hydrocarbons. Some GC patterns of ROZ oil display less n-paraffins and low amounts of

Fig. 9.2.16. Comparison of GC patterns of oils from productive and non-productive wells



short chain hydrocarbons (Fig. 9.2.16 G, H, and I) than those from the productive reservoirs, indicating more intense degradation by meteoric water.

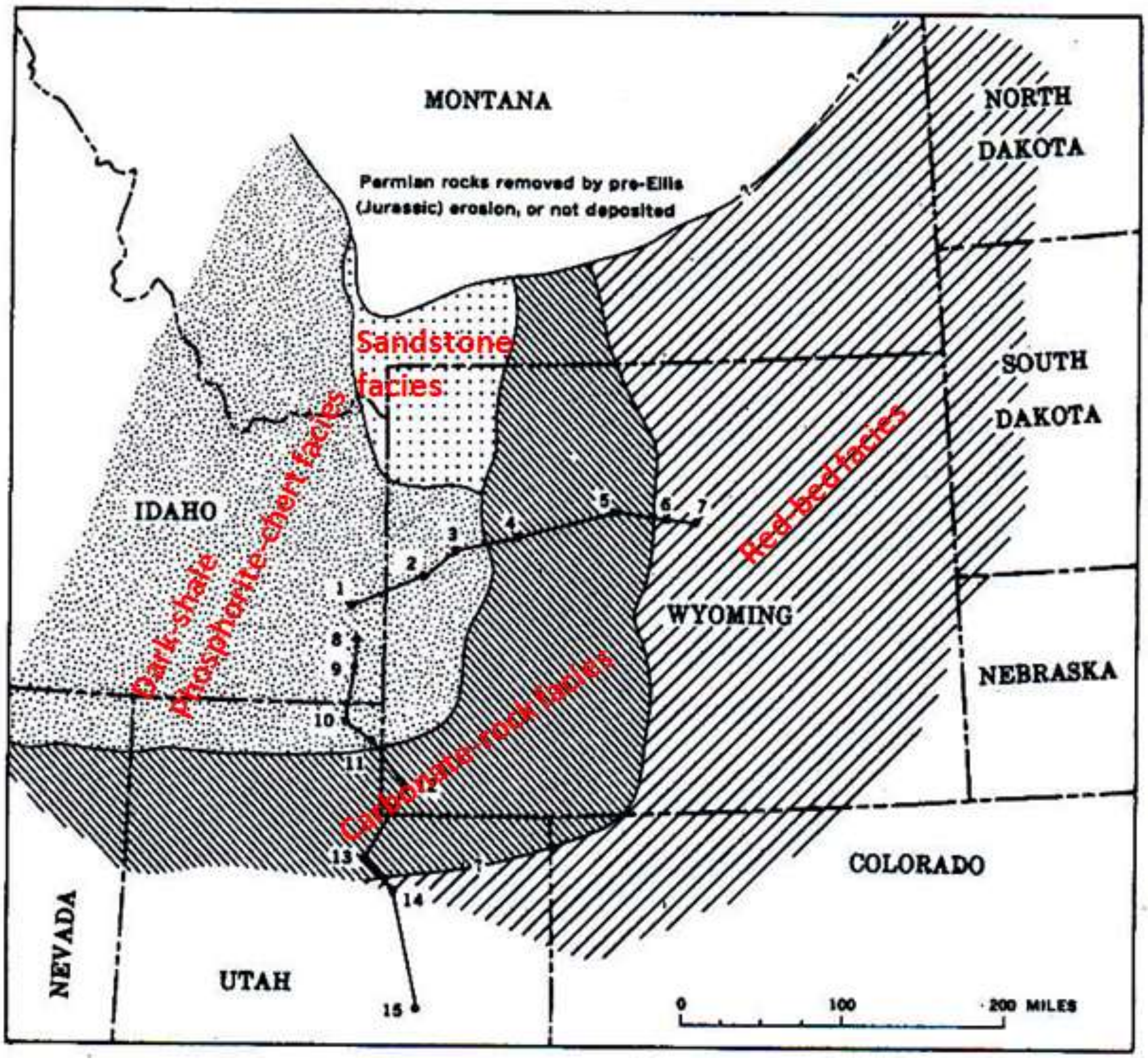
Work reported in Ref 9.15 used low-salinity water to wash crude oil from Venezuela, Oklahoma, and New Mexico in laboratory at the temperature of 80°C and also did numerical modeling. They concluded that water washing is most effective with fresh water, and the C_{15}-fraction of crude oil is first removed from the oil. Degradation of the Tensleep oils in subsurface shows the similar trend with their experimental results, indicating that the Tensleep oil has been experienced various degrees of degradation by fresh meteoric water. Based on the experiments and field observation, (Ref 9.16) concluded that oil is potentially degraded through water washing, oxidation, and biological activities by fresh water rich in oxygen or sulfate ions. Since the Tensleep oil in ROZ has been washed by relatively fresh meteoric water with sulfate ion rich (sulfate ion up to 3000 mg/L), the intensive water wash has played an important role to oil degradation.

Degradation processes reduce the economic value of oil by destroying the paraffins, removing the light ends, oxidizing the remaining fractions of oil, and lowering the API gravity. Degree of the degradation depends on hydrodynamic conditions and the periods of water washing, which are controlled by structural locations and hydrodynamic regime. Therefore, hydrogeological study of the Tensleep aquifers will share some light to predict oil quality in ROZs.

9.2.7 MECHANISMS OF ROZ FORMATION

Extensive ROZ distribution in Bighorn Basin Tensleep is a result of oil generation, multiple episodes of migration and accumulation, and hydrodynamic modification. Tensleep is composed of white and brown eolian sands and grayish dolomite rocks, without organic-rich source rocks for generation of hydrocarbons. It is interpreted by several previous investigators that oil trapped in the Tensleep Sandstone and other Paleozoic reservoirs in the Bighorn Basin was generated from Phosphoria in the southeastern Idaho and west margin of Wyoming (Refs 9.3, 9.14, 9.17). The shale facies of Phosphoria Formation in the Bighorn Basin and in the Cordilleran on the west is characterized by abundant dark-colored, phosphatic, organic-rich calcareous rocks (Fig. 9.2.17). Nearly every well drilled into the Phosphoria marine shales in the Bighorn Basin and elsewhere have live oil shows. Claypool and others (1984, Ref 9.17), through source rock evaluation and basin modeling, concluded that the Phosphoria black shale were mature enough to expulse oil into the Paleozoic reservoirs. In addition, several lines of

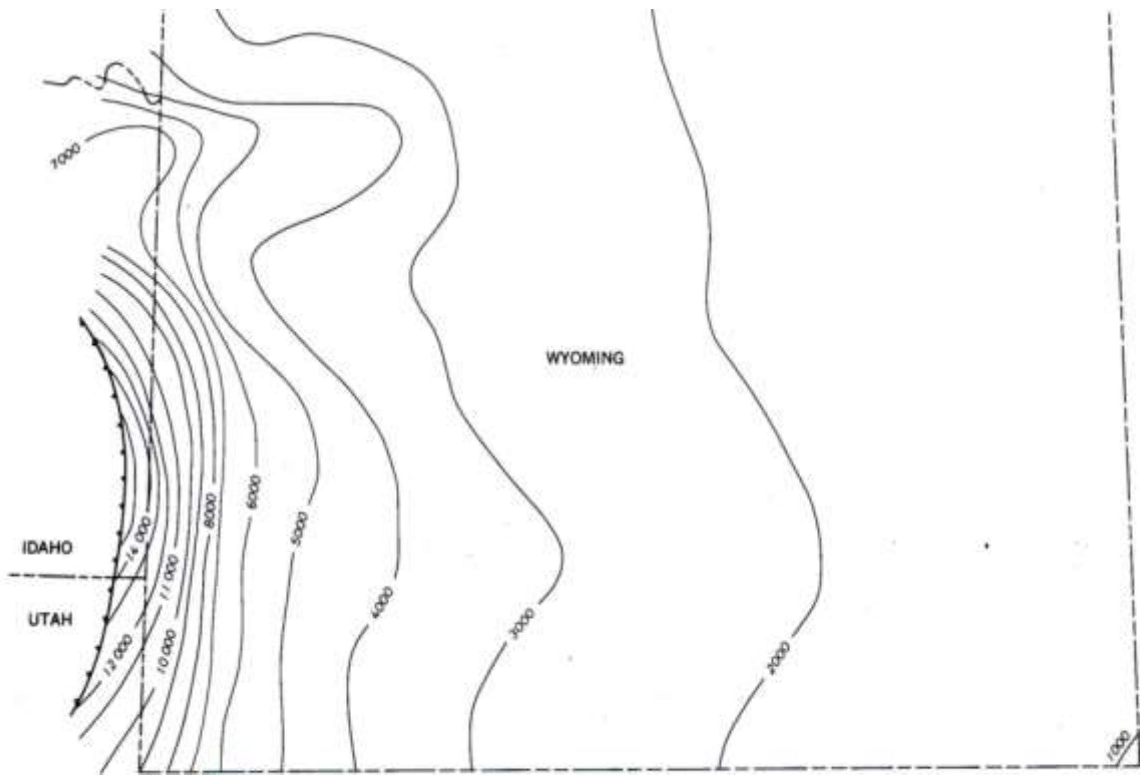
Fig. 9.2.17 - Sedimentary facies of Phosphoria Formation in Idaho, Wyoming, and Utah (modified from Ref 9.14).



chemical parameters, including aromatic-type analysis, infrared measurements on molecular distillation fractions, and some trace elements, indicate the strikingly similar among Phosphoria source rocks, Phosphoria oil, and Tensleep oil in the Bighorn Basin and other Wyoming basins (Refs 9.3, 9.18).

Migration of oil generated from the Phosphoria source rocks to the Tensleep Sandstone reservoirs is favored by the Phosphoria lithofacies distribution and the unconformity between Phosphoria and Tensleep. Phosphoria rocks in the Bighorn Basin are dominated by carbonate rocks, and red beds are located in eastward of carbonate facies. Sheldon (1967, Ref 9.14) contoured a structural map on the top of Permian Formation, and concluded that the Paleozoic sequences in Idaho, Wyoming, and Utah gently dip to the west until the early Cretaceous, and oil migrated from the Phosphoria source rocks into Tensleep Sandstone before Cretaceous time (Ref 9.4). Prior to the Laramide Orogeny, all the Paleozoic strata were very flat, gently updip toward the east from Idaho to Wyoming (Fig. 9.2.18), except some broad structures related to

Fig. 9.2.18 - Structural contour map of Phosphoria Formation prior to the Laramide Orogeny (modified from Ref 9.14)

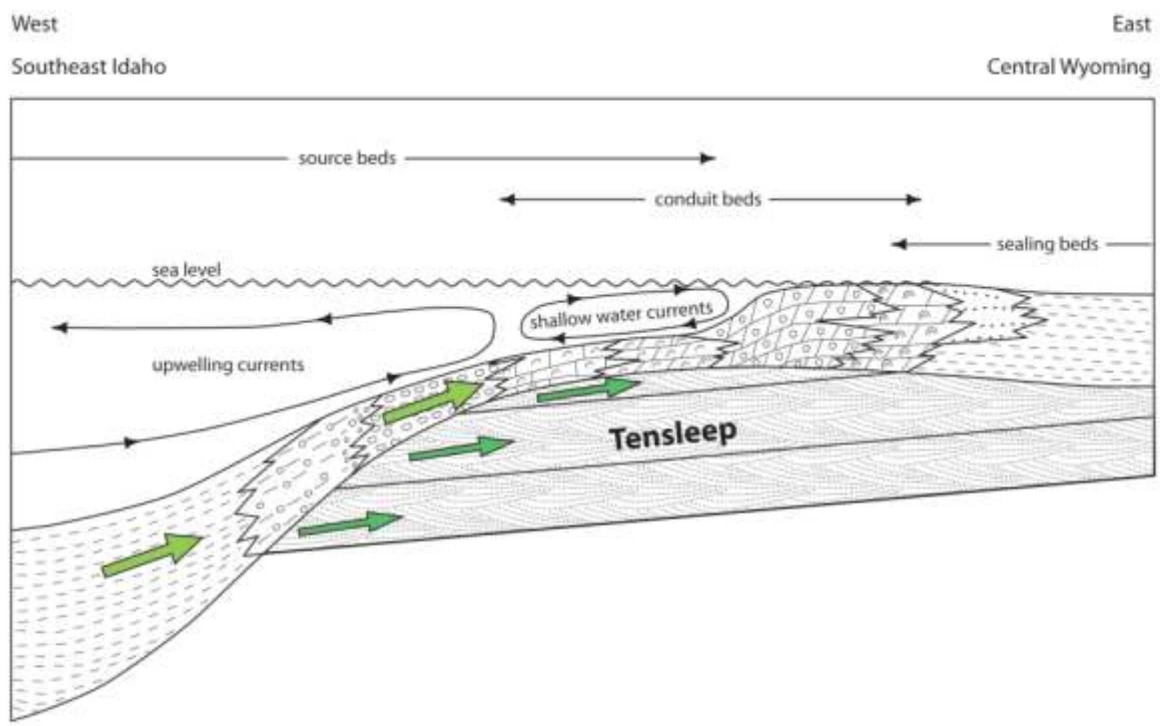


the topography on the surface of the underlying Madison sequence (Ref 9.12). Sheldon (Ref 9.14) interpreted that oil generated from the Phosphoria source rocks in the west migrated into the permeable carbonate rocks in the Bighorn Basin and stopped by the impermeable red beds to the east. Through the regional unconformities between Phosphoria and Tensleep, the Phosphoria oil was also migrated into the underlying Tensleep Sandstone sequence (Fig. 9.2.19).

Tectonic movements with related hydrocarbon migration and accumulation in the Bighorn Basin Paleozoic sequences have been intensively studied by previous geologists

(Todd, T. W., 1963 {Ref 9.12}; Thomas, 1965 {Ref 9.18}; Stone, 1967 {Ref 9.4}; Hoppin and

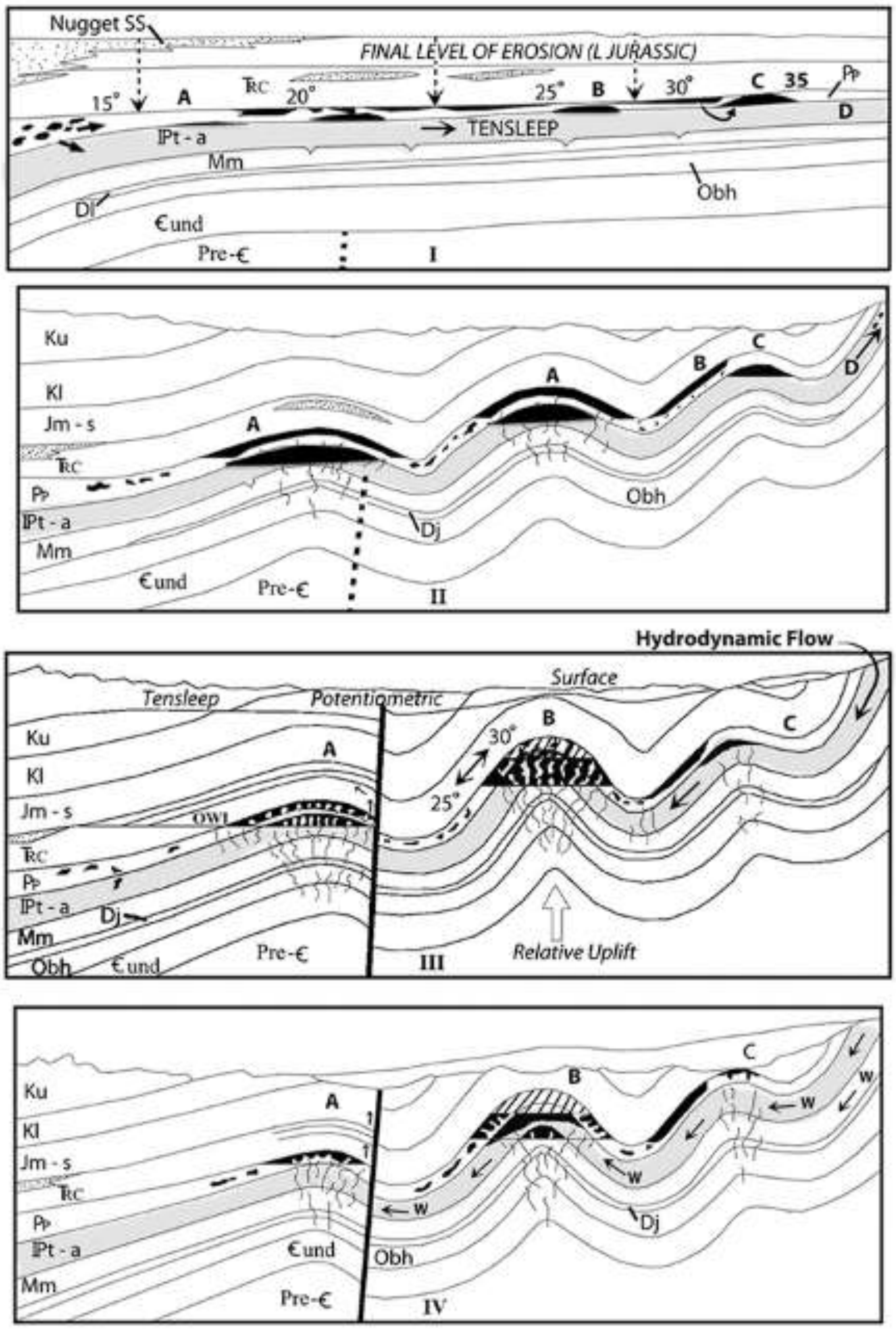
Fig. 9.2.19 - Migration oil generated from the Phosphoria source rocks to eastward Phosphoria carbonates and Tensleep sandstones, modified from Ref 9.14.



Jennings, 1971 {Ref 9.19}; Blackstone, 1986 {Ref 9.20}; Sheldon, 1967 {Ref 9.14}; Pedry, 1975 {Ref 9.21}). Stone (Ref 9.4) generalized the Tensleep Sandstone structure formation and oil migration and accumulation processes before the Laramide Orogeny until present. At the end of Early Cretaceous time, Phosphoria oil is accumulated in stratigraphic or broad structural traps (Fig. 9.2.20 A) of Tensleep Sandstone before the Laramide Orogeny. During the Laramie Orogeny starting from late Cretaceous, a series of anticlines and domes were created in the Bighorn Basin and Bighorn Mountain regions, forming structural traps (Ref 9.4). Oil previous accumulated in the stratigraphic and gentle structural traps re-migrated into the sharp anticlinal structures (Fig. 9.2.20, B). This re-migration left the residual oil in the previous oil-bearing traps. However, the oil left in the pre-Laramide traps is potentially degraded through chemical and physical alterations during a long time period. Pervasive distribution of solid oil residues in the Tensleep sandstones supports this interpretation.

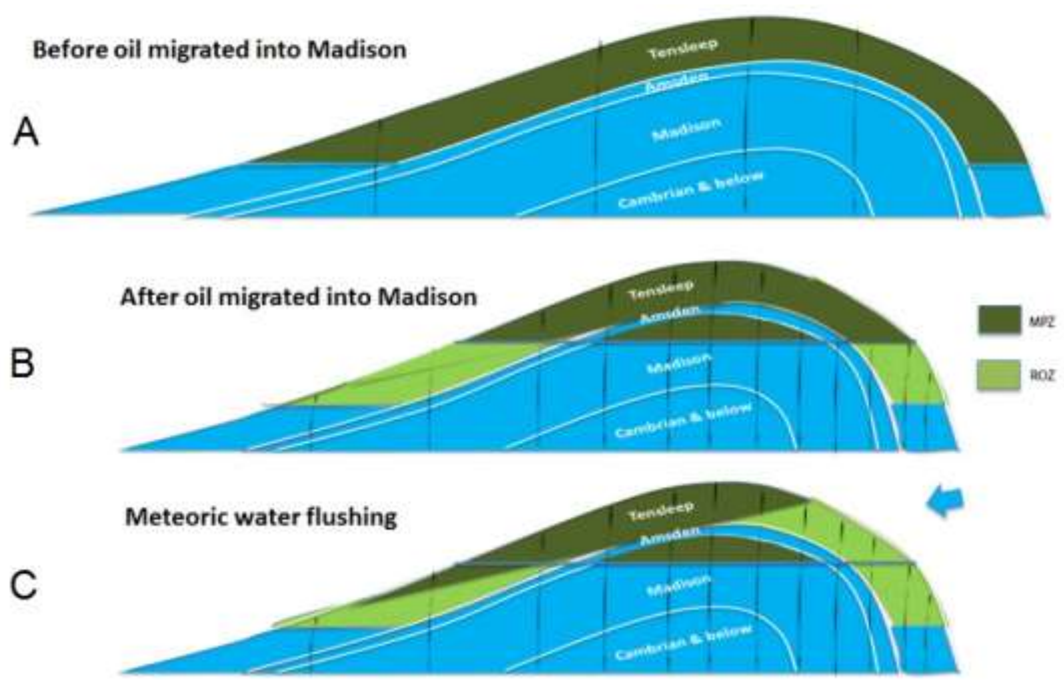
During the early Tertiary time, intensified folding, fracturing, faulting, and differential uplift occurred. Oil in the structural traps adjusted their occurrence in the Paleozoic sequences (Fig. 9.2.20, C). If the faults and fractures served as conduits through all the Paleozoic sequences in some traps with large closure, oil was also migrated into Madison rocks (Figure 9.2.20, D). Oil accumulations before invasion of the meteoric water should be characterized by level oil-water-contact, and a common-pool state include all the Paleozoic oil-bearing strata might be formed with a common oil-water-contact (Ref 9.4). Several episodes of oil migration with continuous tectonic movements left massive residual oil in the previous oil traps

Fig. 9.2.20 - Development of Tensleep structures with oil migration and accumulation (modified from Ref 9.3). See interpretation in text.



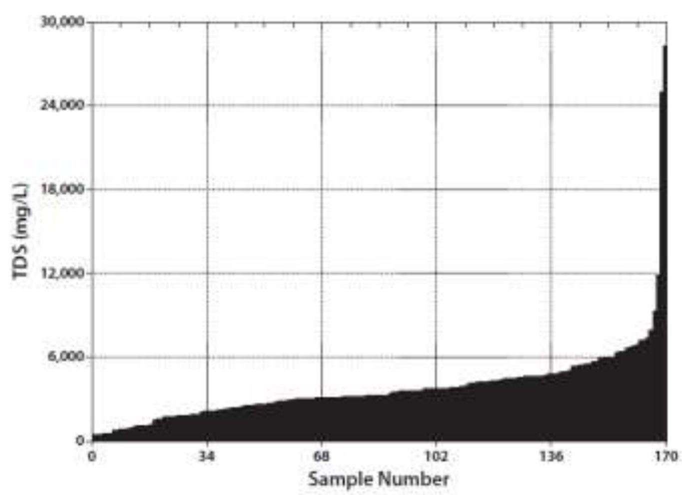
There may be more chance to develop ROZ in the areas with Madison reservoirs. Because the impermeable Amsden Formation separates the Madison and Tensleep, oil could not migrate into the Madison from Tensleep or Phosphoria before heavily fracturing of the Paleozoic rocks with continuous Laramide movements. Therefore, oil currently stored in the Madison reservoirs was migrated from the previous Tensleep or Phosphoria accumulations through faulting and fracturing. As a result, previous oil volume in the Tensleep Sandstone trap is reduced due to migration into the Madison, but a residual oil zone is generated in a portion of the previous Tensleep oil traps due to oil migration out (Fig. 9.2.21).

Fig. 9.2.21 - Creation of ROZ due to migration of oil from Tensleep to Madison. (A) Previous oil accumulation in Tensleep Sandstone. (B) Oil migrated into Madison from Tensleep. (C) Invasion of meteoric water modified the Tensleep oil occurrence, but maybe not Madison.



With erosion on the post-Tensleep rock sequences from the surrounding mountain areas, Tensleep Sandstone is exposed on the surface around the Bighorn Basin mountains areas. Meteoric water flushed into the permeable Tensleep sandstones and initiated the hydrodynamic flow, farther modifying the oil occurrence. Previous oil accumulations with level oil-water-contact were modified to reservoirs with tilted OWC. Oil in the updip location of a trap was swept downward in the trap or spilled out to downdip traps, creating a tilted OWC (Fig. 9.2.20D and 21C). As a result, ROZs are generated below the tilted OWCs. If most of oil is swept into the downdip traps, ROZs may be formed in the previous trap without MPZ, and the entire structure was not developed during the primary and conventional secondary production. A structural map created by Zapp (1956, Ref 9.7) marks 12 Tensleep reservoirs with tilted OWC, indicating ROZs exist under the OWC in these reservoirs. Ref 9.4 mentioned four more Tensleep reservoirs with tilted OWC in his research. Several other scientists (Baggs and Espach, 1960 {Ref 9.22}), and Ref 9.1) also documented Tensleep reservoirs in the Bighorn Basin with tilted oil-water-contact.

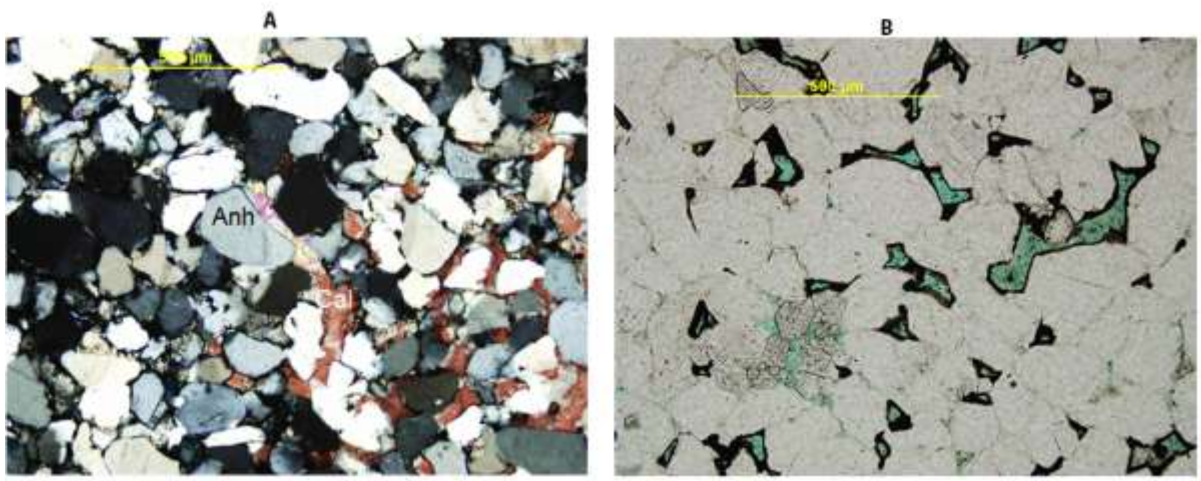
Fig. 9.2.22 - Total dissolved solids in Tensleep Formation water samples



Meteoric water invasion into the Tensleep Sandstone is also evidenced by low formation water salinity in the Tensleep reservoirs, Bighorn Basin (Fig. 9.2.22). 9.4% of the 170 collected formation water samples possess TDS values less than 1000 mg/L, categorized as fresh water. 18% of samples have TDS values less than 2000 mg/L. The highest value of TDS in all these water samples is 28,215 mg/L, and only 3 samples possess the TDS values greater than 10,000 mg/L. Both dolomite and anhydrite were precipitated in the Tensleep sandstones, indicating that the connate water salinity should be much greater than the salinity of 36,000 mg/L as normal seawaters. The TDS values of the Tensleep formation waters indicate that most of the Tensleep sandstones have been affected by meteoric water invasion. The potential recharge areas for meteoric water are located on the surrounding mountain terraces or uplifts on the basin slope with exposure of the Tensleep sandstones to the surface.

Tensleep sandstones were deposited in an arid conditions, and the primary cements are dominated by microcrystalline dolomite and anhydrite, with trace amounts of other evaporitic minerals. Any other chemical cements must be generated through diagenetic modifications with formation water changes during the tectonic evolution. Discovery of secondary calcite in the Tensleep sandstones provides another evidence for meteoric water invasion and degradation of Tensleep oil (Figure 9.2.23A). The organic carbon-rich secondary calcite is the result of replacement of anhydrite. Meteoric water flushed into the Tensleep sandstones, lowering the formation water salinity and de-stabilize anhydrite. Degradation of oil by meteoric water generated bicarbonate. Calcium released by de-stabilization of anhydrite and generated bicarbonate facilitate replacement of anhydrite to secondary calcite. Degradation of oil left solid hydrocarbon residue on the grains surfaces, which is commonly observed in the Tensleep sandstones (Fig. 9.2.23B). Todd (1963, Ref 9.12) also interpreted that secondary coarse euhedral dolomite replacement of microcrystalline dolomite, observed in some Bighorn Basin Tensleep sandstones,might be relate to oxidation-reduction reactions of petroleum by flushing meteoric water.

Fig. 9.2.23 - Secondary calcite partially replacing anhydrite (A) and solid hydrocarbon coating quartz grains (B).



9.2.8 SUMMARIES/SUGGESTIONS FOR FUTURE WORK

Based on the current study, the potential areas for Massive Tensleep ROZs development are: (1) the wedge-shaped intervals underneath the tilted OWCs in existing Tensleep reservoirs; (2) surrounding areas of existing Tensleep reservoirs, especially the reservoirs with production from Madison and/or older formations; and (3) un-developed oil-bearing anticlines.

Oil quality in ROZ is controlled by the degree of biological, chemical, and physical degradation. The current oil accumulation is the results of multiple episodes of migration, accumulation, and occurrence adjustments. As a consequence, the quality of residual oil left in ROZs during the late migrations should be better than ones left during early migrations. ROZs underneath the tilted OWCs are formed by the latest modification of oil accumulations, and oil quality within this type of should usually be better. If this type of ROZs is satisfied for recovery, combined development of both ROZ and MPZ will be economically advantageous.

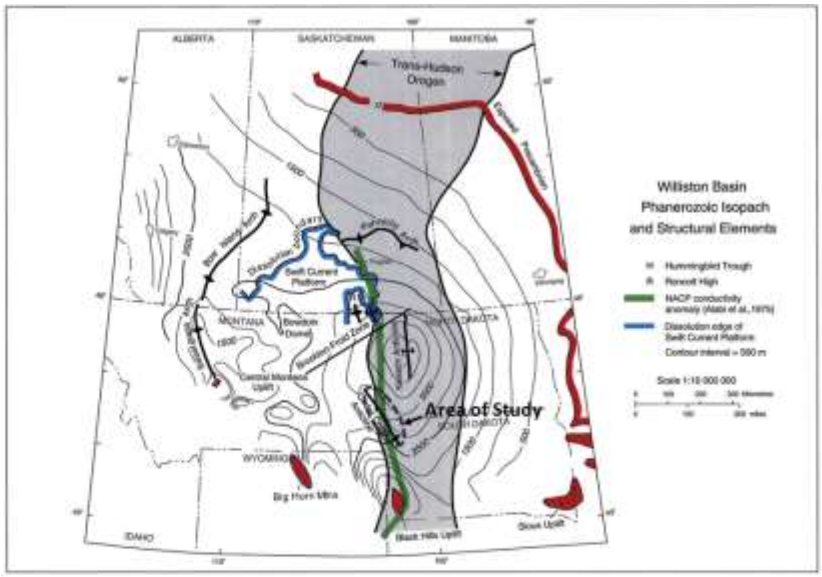
Oil quality of ROZs in some un-developed structures are probably similar to oil in ROZs below the tilted OWC in existing reservoirs, because oil in this type of ROZs has experienced the similar degradation as oil in ROZs underneath tilted OWC. However, there are no existing facilities for development in these structures with ROZ. More investments will be needed to recovery oil from this type of ROZs.

9.3 SOUTHERN WILLISTON BASIN

9.3.1 BACKGROUND

A number of important hydrologic and related petroleum studies have been done in the southern Williston Basin (Fig. 9.3.1) in attempts to document the presence of hydrodynamic forces. Two studies even postulated the time variable nature of those forces (Refs 9.24, 9.25). A large portion of those have been accomplished with the purpose of identifying the generalized subsurface pathways of flow that have affected the position of modern oil entrapments (Refs 9.3, 9.24, 9.26).

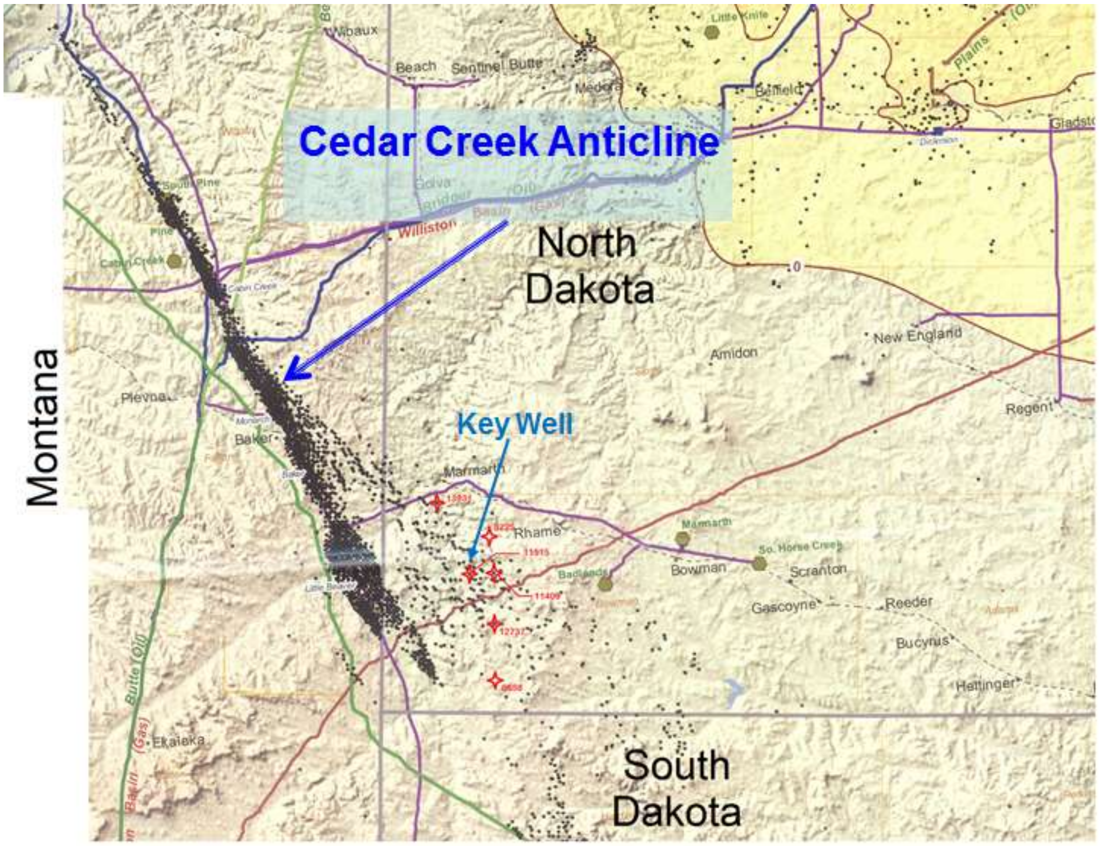
Fig. 9.3.1 – Map of the Williston Basin Region Showing Major Tectonic Features (adapted from Ref 9.23)



The Cedar Creek Anticline (CCA) and Billings nose area just to the north of the CCA are two regions that have received some notoriety as the reports there (Refs 9.2, 9.26) assisted with theorizing the source of meteoric water, the pathways of subsurface flow of water, and the location of the displaced oil; i.e., primary oil that had been moved from a paleo entrapment to a secondary trap. To the author’s knowledge, this study, nor none of the other work in the Williston Basin, attempted to document where that oil had been originally entrapped (i.e., ROZ locations). The attributes of the ROZ reservoirs and composition of its fluids had therefore escaped documentation.

The place to start with this Willison Basin study was to develop an understanding of the tectonic history of the region, review the pertinent literature, and to select certain areas to investigate utilizing the “cookbook” methods outlined in Chapter 5. The area chosen to look at initially was the Cedar Creek anticline (Figs 9.3.1 and 9.3.2).

Fig. 9.3.2 – Cedar Creek Anticline Study Area Map Showing Location of Key Well

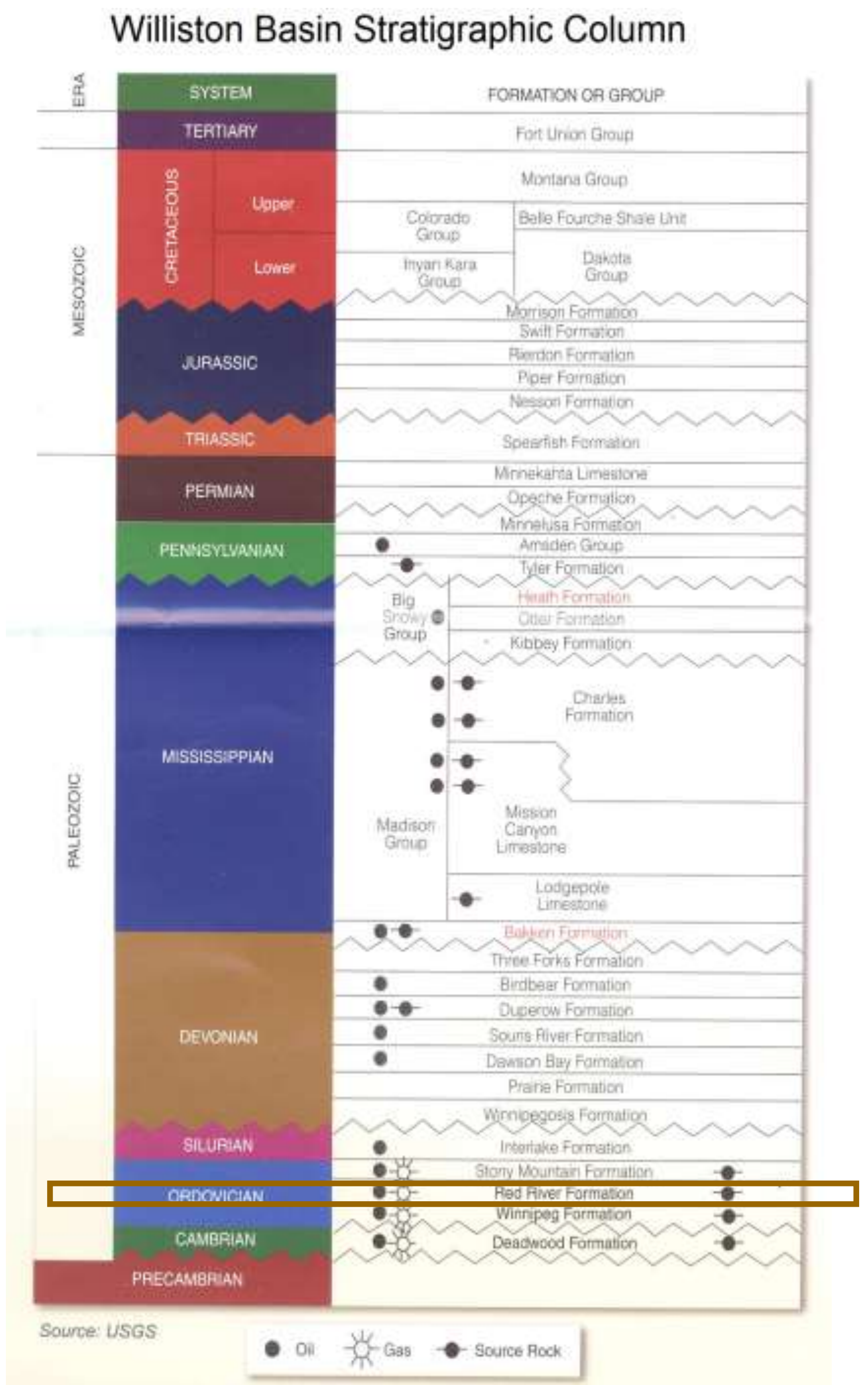


As was the case for the Permian and Big Horn Basins, the ancestral Williston Basin was much larger than the current one as it extended much further south and west of the modern feature commonly referred to as the Williston Basin. The Laramide orogeny created a significant alteration to the ancestral basin and two prominent features, the Black Hills and the Big Horn Mountains (Ref 9.26) have played a significant role in the paleo displacement of oil in the ancient entrapments during the Tertiary Period to Present.

Since the literature has effectively documented the hydrodynamics of this region of North Dakota and including the Cedar Creek anticline area (Ref 9.27), it was decided to begin to look there for evidence of ROZs. At first, it seemed appropriate to look at to the west of the current entrapments in hopes of finding shows that would have indicated the paleo entrapment was at the apex of the anticline prior to the development of the northeastern hydrodynamic oil displacement and up-gradient from the current production. After a search on the western flank revealed uninteresting shows of oil, it was decided to look to the east.

The production associated with the CCA is predominately the Ordovician Red River Formation (Fig. 9.3.3) so the study concentrated it efforts there.

Figure 9.3.3


Williston Basin Stratigraphic Column
ERA
SYSTEM
FORMATION OR GROUP
TERTIARY
Fort Union Group
MESOZOIC
CRETACEOUS
Upper
Lower
Montana Group
Colorado Group
Belle Fourche Shale Unit
Inyan Kara Group
Dakota Group
JURASSIC
Morrison Formation
Swift Formation
Rierdon Formation
Piper Formation
Nesson Formation
TRIASSIC
Spearfish Formation
PERMIAN
Minnekahta Limestone
Opeche Formation
Minnelusa Formation
PENNSYLVANIAN
Amsden Group
Tyler Formation
Big Snowy Group
Heath Formation
Otter Formation
Kibbey Formation
PALEOZOIC
MISSISSIPPIAN
Charles Formation
Madison Group
Mission Canyon Limestone
Lodgepole Limestone
Bakken Formation
DEVONIAN
Three Forks Formation
Birdbear Formation
Duperow Formation
Souris River Formation
Dawson Bay Formation
Prairie Formation
Winnipegosis Formation
SILURIAN
Interlake Formation
ORDOVICIAN
Stony Mountain Formation
Red River Formation
Winnipeg Formation
CAMBRIAN
Deadwood Formation
PRECAMBRIAN
Source: USGS
Oil
Gas
Source Rock

9.3.2 KEY WELL IDENTIFICATION

The availability of data can be an issue in working through the “cookbook” steps for a thorough ROZ search. To our good fortune in our case here, various types of well data were readily available from the excellent and modern, annual-fee-accessible, North Dakota Industrial Commission (NDIC) website (https://www.dmr.nd.gov/oilgas/). A review of wells in the area of our study, prior to finding the key well, showed numerous dry holes were present in Bowman County with the repeated drilling efforts apparently repeatedly encouraged by the quality of oil shows encountered. The review was able to find some well reports, scout tickets, drill stem test data, core results and mudlogs all indicative of live-oil ROZs. One particular well possessed more available data than most others and is called our key well. The well was drilled 1980’ from the south line and 1200’ from the east line in section 19, T131N-R105W, Bowman County, North Dakota.

The first piece of anecdotal evidence of a ROZ was the well site consultant’s report (Fig. 9.3.4) below. The bold lettering (author added) are emphasized as indicators of the presence of either mobile or immobile oil in the formation.

Figure 9.3.4 – Well Site Consultant’s Summary Well Report and Conclusions

The mudlogger arrived on location Sunday June 2, 1985. The well was drilling at a depth of 7975’ in the Mississippian Lodgepole formation. No significant sample or mud log shows were present in uphole formations from the Lower Mississippian to the top of the Red River formation.

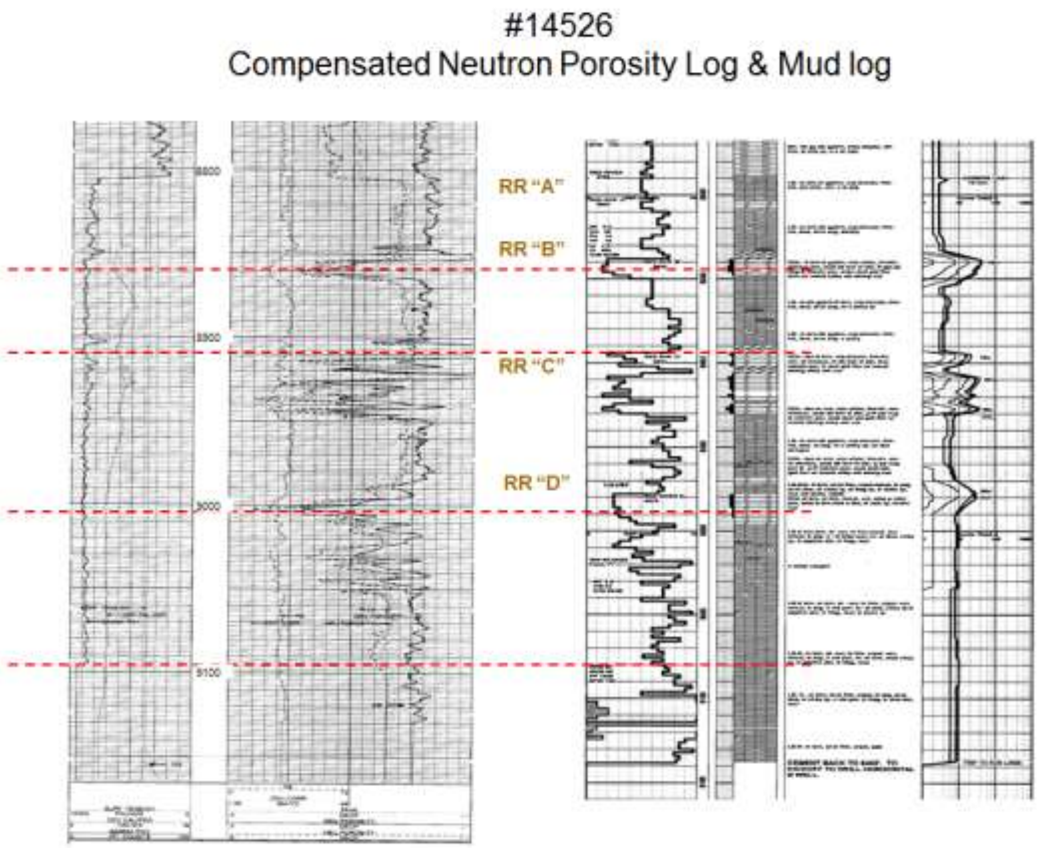
Oil shows existed in four zones within the Red River formation. The Red River “A” zone had a good sample and mud log show and was drill stem tested with significant oil recovery. The Red River “B” had minor sample shows of oil, but no significant gas increase was logged. Electric logs show marginal porosity and high salt water saturations. **The Red River “C” zone had good sample shows. The upper portion 9081’-9092’ had a significant gas increase.** In addition, the interval 9096’-9143’ was cored.

The core indicated some oil saturation but also high water saturation. A drill stem test of the interval 9079’-9143’ recovered 87’ of drilling mud, 657’ of oil cut salt water, and 5084’ of gas cut salt water with a **trace of oil. Electric logs confirm the negative drill stem test but calculate oil saturations.** The Red River “D” zone had poor dolomite porosity development with a **minor sample show**. No gas increase was logged and electric logs show it to be tight.

In the conclusion of the evaluation team, the Red River “A” zone offered the only possibility for primary hydrocarbon production and was judged to be non-commercial. Consequently, the well was plugged and abandoned.

Wireline and mud logs were available as well. Figure 9.3.4 illustrates a gamma ray density log (left track on left panel) and neutron log (right track) of the well while the right panel is the mud log with the left track the drilling time and the right track provides the gas shows that are derived as the gas breaks out of the drilling mud at the surface. The multicomponents of the the gas shows emanating from the circulating mud are illustrated by the multiple curves on the right track.

Figure 9.3.4 – Key Well Neutron and Mud Log



This key well is located just to the east of the CCA productive trend from the Red River B formation. It also lies downdip of the structural apex of the Cedar Creek Anticline (Fig. 9.3.2). We can conjecture that the well must have been a frustration to the company drilling it as it possesses all of the indicators suggesting an oil producer. A drill stem test was performed on the Red River "B" interval but recovered only water. Thus, and in spite of the good oil shows, the interval apparently lacked the free (mobile) oil component to make it a conventional drilling and completion success. It was plugged as a dry hole.

9.3.3 KEY WELL SUMMARY

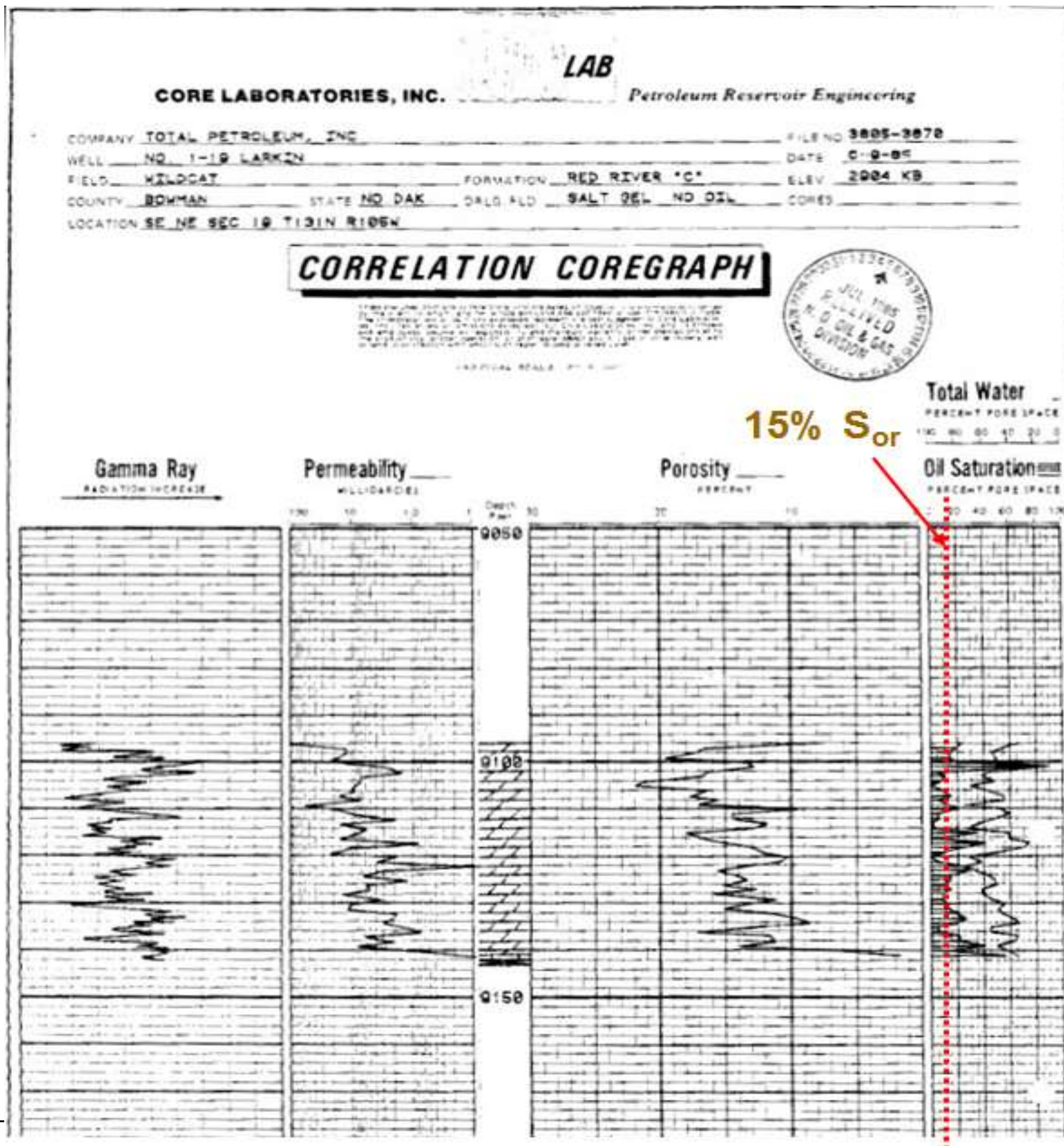
In the key well, oil shows were reported in four zones within the Red River formation. The Red River "A" zone had a good sample and mud log show and was drill stem tested with some (mobile) oil recovery. The Red River "B" had minor sample shows of oil, but no significant gas increase was logged. Electric logs show marginal porosity and high salt water saturations. The Red River "C" dolomite interval had encountered shows of oil nearby wells and had good sample shows in the upper portion 9081'-9092' where it had a significant gas increase. The well operator tripped out of the hole to core the remaining "C" zone interval (9096'-9143' was cored). Figure 9.3.6 is the core report. The core laboratory testing indicated some oil saturation but also high water saturation leaving the operator to conclude the zone lacked the mobile oil component.

A drill stem test of the interval 9079'-9143' recovered 87' of drilling mud, 657' of oil cut salt water, and 5084' of gas cut salt water with a trace of oil. Electric logs confirm the negative drill stem test but calculate oil saturations.

The Red River "D" zone had poor dolomite porosity development with a minor sample show. No gas increase was logged and electric logs show it to be tight.

In the conclusion of the on-site well evaluation team, the Red River "A" zone offered the only possibility for primary hydrocarbon production but was judged to be non-commercial. The Red River "B" and "C" zones were not capable of producing primary oil. Consequently, the well was plugged and abandoned.

Figure 9.3.6 - Test Results from the Core of the “C” Zone in the Red River Fm in the Key Well



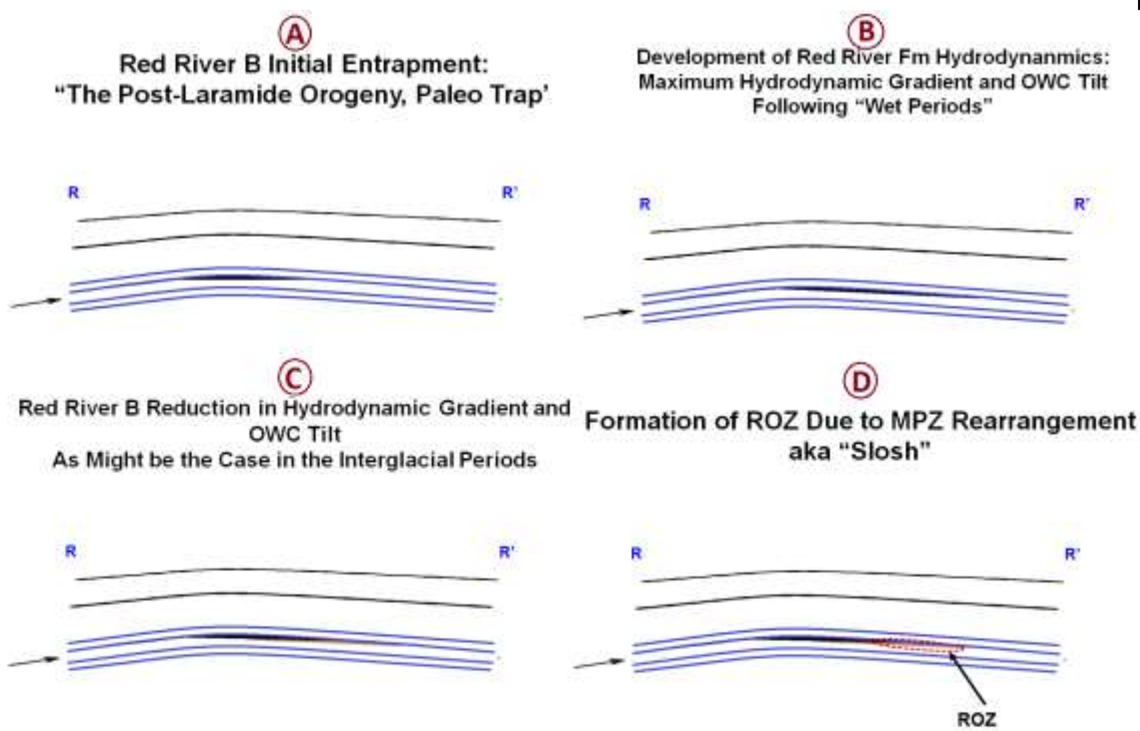
The well results provide most of the classical evidence of a ROZ according to the guides provided in Chapter 5 (ROZ “Cookbook”). The aggregate thickness of the combined A, B and C zones would provide sufficient oil in place and entrained gas to establish commercial production on depressuring the reservoir.

9.3.4 ROZ CONCLUSIONS

The key well presented above does not appear to be an isolated case in this area of North Dakota. Fig. 9.3.5 provides a structural cross section along strike (NW to SE) and downdip to the production along the anticlinal trend. Note that the structural position of the ROZs is relatively flat in the area wells but the porous dolomite zones of the Red River do vary somewhat in quality and thickness. The Red River "C" has not been widely productive along the anticlinal trend but it appears to be highly prospective as a ROZ interval that can reach up to 60 feet in thickness.

Seeing the nature of the widespread shows on the down-gradient side of the CCA was, at first, an enigma with the aforementioned paleo entrapment model that would have been present at the apex of the CCA. What we have come to understand, however, is that the variable hydrodynamic gradient that one would expect given the Pleistocene and recent glacial periods, has led to the shows observed NE of the CCA. Fig. 9.3.6 attempts to capture the origin of the ROZs in the region as the oil column has been displaced further to the NE in the wet periods while, today, has moved back towards the anticline. This leaves a very large area that

Figure 9.3.7 – Type 3 ROZ with Variable Hydrodynamic Gradient ("Slosh") Indicative of Red River Formation ROZ in Bowman County, North Dakota



has seen moveable oil but now contains only moveable water and residual oil.

As mentioned above and after all the shows of oil, the company decided not to try a completion and the well was abandoned as a dry hole. As Chapter 5 (ROZ "Cookbook") points out, the oil and gas shows were excellent here, much like a primary producing well will have but, in fact, indicative of a well here that would produce no oil under primary or secondary operations. As we know now, these signs point to an excellent ROZ target for EOR.

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Chapter 10 – SUMMARY AND CONCLUSIONS

To our knowledge, this is the first report or paper to address the major topics related to residual oil zones. Previous reports and articles have touched on many aspects of zones beneath oil/water contacts but a report covering the origins, distributions, science, properties and tools for identifying ROZs has not been attempted. What has encouraged this report of course is the development of EOR techniques that can recover ROZ oil commercially. Nowhere is that more evident than in the San Andres formation of the Permian Basin region of Texas where many projects are attempting to commercially move oil out from the immobile oil intervals we now call residual oil zones. It is there that the convergence of available, reliable, and affordable CO_2 with a seemingly inexhaustible oil resource within the ubiquitous, dolomitic formation called the San Andres has fostered new innovation.

Once the field-specific commercial projects have created the attention, a regional study to establish the maps and common characteristics of the resource is needed. This report does that with the establishment of the origins of the ROZs and mapping their trends. The resulting exhaustive exercise has led to a better understanding of the origins of the types of ROZs. That, in turn, led to the discovery that the Type 3 ROZ intervals lie not only below the major fields but can be found between the fields therefore having no main pay zone above them. It is fair to say that the research reported in this report has helped cause the implementation of what is now termed a Greenfield ROZ field demonstration project where no production from the project area reservoir had occurred prior to the CO_2 EOR project. Previous ROZ projects had all been developed by extending the wells to intervals below the oil/water contact (brownfields).

The rock that forms the ROZ reservoirs represent the classic ‘trap-quality’ reservoirs representative of high energy depositional environments. In a carbonate shoal/reefal environment, these trend along and parallel to the ancient shorelines. Reconstruction of the time-varying basin geometries with their shorelines at various times during the San Andres was helpful in mapping the ROZ trends. Also useful were the producing San Andres (main payzone) fields that are most often relics of a porosity closure atop the laterally swept portions of the reservoirs. Those tools allowed a general definition of the fairways of sweep which could then be checked with wireline logs, drill stem tests, and mud log data to confirm the mapping. A minimum criterion of 100 feet of thickness was used to define the limits of the fairways.

In defining the regional characteristics of the ROZs, common trends in their rock and fluid attributes can be identified. Examples of these are the bow shaped character on resisitivity and porosity logs, suppressed sonic log “bow” shape suggesting the intervals have a strong component of secondary porosity, and near-constant photoelectric crossectional log values of 3 barnes/electron. This led the research into why the ROZs were different than the main pay zones and deep into the field of biogeochemistry. The manifestations of pervasive anaerobic bacteria activity clearly have affected the oil, water and rock properties as reported in Chapter 4. Since the microbes have to live in water and thereby very different from mobile oil reservoirs, it helps explains why this field of study has been generally overlooked in the past. A more complete picture of their effects is now apparent with the conversion of anhydrite to calcite to dolomite and thus releasing sulfur in the form of H_2S and other sulfurous chemicals that reside in the oils and water.

Although a lot can be gleaned from the regional work, much work remains in acquiring samples and testing of the oils and waters to identify trends and end states in the reservoir fluids. Of special interest are the properties of the oils as they appear to vary with depth and proximity to the source of and distance to the flushing waters and the late stage, pervasive diagenesis (dolomitization) that has contributed to the oil-wet nature of the ROZ reservoir.

Regional mapping of the ROZ resource also precipitated a curiosity regarding the size of the ROZ oil resource. A large portion of the effort herein was dedicated to identifying the richest oil bearing ROZ areas and then acquiring the wireline log data to develop cross sections and assessing the oil in place resource. This effort is described in Chapter 7. Some porosity and oil saturation parameters were necessary to use in the screening and 8% porosity and 20% oil saturation were chosen as cutoffs. The resource was then subdivided into high and low quality categories in order to attempt to address the commerciality issues of the in-place resource. Archie calculations[13] were predominately used to assess the oil saturations but checked with core and mudlog data where appropriate and available. Calibration with some indeptendent industry work at the Tall Cotton Greenfield ROZ CO_2 EOR project was used as a calibration point as well.

Some earlier work, prior to this study, had utilized similar resource assessment methodologies and found a brownfield resource of 30.7 billion barrels of OIP beneath 56 fields on the Central Basin Platform, Northern Shelf and Eastern Shelf regions of the Permian Basin. But the challenge of this new work was to extend the assessment work to the extensive

[13] Archie, G. E., 1952, Classification of carbonate reservoir rocks and petrophysical considerations: AAPG Bulletin, vol. 36, no. 2, p. 218–298

Greenfield areas requiring use the recently generated maps of the ROZs within the Permian Basin San Andres formation presented in Chapter 3. That, together with the identification of the ROZ interval and calculated residual oil saturations, could then be used to estimate the OIP resource base. The results of the regional OIP resource assessment has determined that, in the 12-county area studied, 135 billion barrels (Bbbls) of oil in place is of high quality; i.e., porosity greater than 8% and oil saturations greater than 25%), that an additional 56 Bbbls of lower quality OIP is present for a total of 191 Bbbls. Of that amount, 17.5 billion barrels are commercially viable in the original 4-county area using CO_2 EOR techniques using an oil price of $80/barrel and $1.92/mcf. To put that in perspective, approximately 32 Bbbls of oil have been produced in in the Permian Basin from the date of initial production to present. It is also instructive to note that the study area included four southern counties (Midland, Crane, Upton and Ward) that had insignificant San Andres ROZs but that the ROZs were in the overlying Grayburg Formation thereby not included in the San Andres resource numbers quoted above.

Advancements in the drilling and completion technologies associated with the unconventional reservoirs has led to a revolution in oil and gas production in the U.S. The progress to date has been almost exclusively tied to shale resources like the Bakken, Eagle Ford, Marcellus, and Wolfberry along with a few other formations. Transference of those technologies to carbonate rocks has lagged behind but the ROZ understandings are currently leading to application of the drilling and completion techniques to the upper sections of the ROZ intervals. Some case histories are included herein which demonstrate that some mile-long horizontal laterals appear capable of producing 250,000 barrels of oil. This new horizontal play, dubbed herein as Depressuring the Upper ROZ (DUROZ) or Depressuring EOR (DEOR) is now well underway in the northern reaches of the ROZ study area. Timely technology transfer events during the course of this study have assisted in the understanding of the science and properties of ROZ rocks and oils and thereby contributed to the rapid expansion of the play. Because the play is focused in the ROZ where no mobile oil exists, the demonstration of the process of mobilizing residual oil by depressurization (aka dewatering) of a reservoir is apparent. Extension of the San Andres DUROZ play will undoubtedly occur in other formations and basins where ROZ reservoir and fluid conditions are right.

The base of the ROZ interval is sometimes a shaley dolomite providing a bottom to the lateral sweep creating the ROZ. It was a third tier objective of the project to attempt to get some seismic reflection data contributed and the project would reprocess the surveys in an attempt to view the base of the ROZ. After some study, a particularly good area was chosen that had seismic data available but the access and cost of the reprocessing proved to be prohibitive. Future work would be well served to include a new attempt to conduct such a seismic study.

One of the challenges of CO_2 EOR has always been the magnitude and duration of capital expenditures prior to producing incremental EOR oil. The DUROZ play allows quick returns while building some of the infrastructure to be used in the EOR project. Future studies and demonstrations of CO_2 EOR projects following behind the DUROZ wells are recommended.

The worry with good research and its resulting products is that it only applies to one particular situation – in our case the San Andres formation of the Permian Basin. The project attempted to address that concern with two subprojects in two other basins – the Big Horn and Williston Basins. Both were documented in the literature to have multiple stages of tectonics that postdated the initial subsidence and oil entrapment stage. The Big Horn Basin work reported herein was accomplished by the Enhanced Oil Recovery Institute in Wyoming with the input from project personnel. The Williston Basin study was conducted primarily by this project's personnel but with some consultation help from the Energy and Environmental Research Center of the University of North Dakota. Results of both studies were very encouraging; likely large regional Type 3 ROZ resources are present in the Tensleep formation in the Big Horn Basin and the Red River formation in the Williston formation.

Finally, this study has effectively negated two oft quoted myths: 1) that reservoir targets for CO_2 EOR are small and localized and 2) that transition zones are the only way to view oil situated below the oil/water contacts. Since neither are true, commercial opportunities for exploiting ROZs are underway and showing tremendous promise. Finally, their ability to provide a safe home for stored CO_2 via extension to carbon capture and storage could be enormous.